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Evaluation of Health and Environmental Effects of Extra High Voltage (EHV) Transmission

(U.S.) Office of Radiation Programs
Washington, DC

Jun 80

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June 1980

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Evaluation of Health and Environmental Effects of Extra High Voltage (EHV) Transmission

Final Report

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In March 1975 to respond to concerns about the possible adverse health and environmental effects of Extra High Voltage (EHV) transmission lines, the Environmental Protection Agency requested data and information from the public (through a Federal Register Notice) on the health and environmental effects of 60 Hz transmission lines energized at 700 kV or higher. A review and analyses of more than 50 replies totaling over 6,000 pages is presented in this document.

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In March 1975 to respond to concerns about the possible adverse health and environmental effects of Extra High Voltage (EHV) transmission lines, the Environmental Protection Agency requested data and information from the public (through a Federal Register Notice) on the health and environmental effects of 60 Hz transmission lines energized at 700 kV or higher. A review and analyses of more than 50 replies totaling over 6,000 pages is presented in this document. Additional research information has been included where appropriate.

The health and environmental aspects of EHV transmission divide into two broad areas: possible effects caused by the electric and magnetic fields in the vicinity of the line, and effects caused by electrical discharges from the line. The first area of discussion includes a review of the methods used to calculate and measure the fields,

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a discussion of the effects of such current and voltage on humans who may come into contact with these objects, and a discussion of the effects of transmission line fields on living organisms. The second area includes a discussion of the discharge phenomenon, principally corona, and the various side effects of concern resulting from the corona process. The side effects of concern include the production of ozone and other gaseous effluents, the generation of audible noise, and the production of electromagnetic noise in the radiofrequency spectrum.

Although this document presents material representing scientific results, it has been written in layman's language.

ORP/SEPD 80-13

EVALUATION OF HEALTH AND ENVIRONMENTAL EFFECTS OF EXTRA HIGH VOLTAGE (EHV) TRANSMISSION

Final Report
February 1979

Prepared under Contract No. 68-01-4604

June 1980

Project Officer
David E. Janes

U.S. Environmental Protection Agency
Office of Radiation Programs
Washington, D.C. 20460

FOREWORD

The Office of Radiation Programs carries out a national program designed to evaluate the exposure of man to ionizing and nonionizing radiation and to promote the development of controls necessary to protect the public health and safety and assure environmental quality.

Office of Radiation Programs technical reports allow comprehensive and rapid publishing of the results of intramural and contract projects. The reports are distributed to groups who have known interests in this type of information such as the Nuclear Regulatory Commission, the Department of Energy, and State radiation control agencies. These reports are also provided to the National Technical Information Service in order that they may be readily available to the scientific community and to the public.

Comments on this report, as well as any new information, would be welcomed; they may be sent to the Director, Surveillance and Emergency Preparedness Division (ANR-461), Office of Radiation Programs, U. S. Environmental Protection Agency, Washington, D. C. 20460.

Floyd L. Galpin
Acting Director, Surveillance
and Emergency Preparedness Division

SUMMARY

In March 1975, the U.S. Environmental Protection Agency published a notice in the Federal Register requesting data and information on the health and environmental effects of 60 Hz transmission lines energized at 700 kV or higher. This action was taken in response to concern which had been expressed over possible adverse health and environmental effects of Extra High Voltage (EHV) transmission lines.

Over fifty (50) replies, totaling over 6000 pages, were received in response to the Agency's request. A review and analysis of the received information has now been completed and is presented in this document. The intent of the notice and subsequent analysis was to assist the Agency in (1) categorizing potential adverse effects and (2) determining the need to provide guidance to Federal agencies or for future regulatory action.

The issues involved in the health and environmental effects of EHV lines are many, and concern is widespread; as was evidenced by the diverse range of corporate, agency and individual responses to the notice. As would be expected for a problem of such importance, the flow of new information continues, and important research is still ongoing. Thus, it cannot be expected that an analysis of pre-1975 information would tell the whole story.

In preparing this document, information in addition to that submitted in response to the Federal Register Notice has been utilized, when such information was known and felt to be important. However, since the scope and allocated resources were for an analysis of the FRL responses, a formal assessment of all currently available information could not be performed.

Some respondees who reviewed the interim report recommended that the final report reflect an analysis which includes information developed since the FRL sibmittals. Such an analysis is not possible under the existing contract; and while such an analysis would be useful, the concomitant delays might be counterproductive.

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The analysis which has been performed is felt to be highly important for the purpose of assisting the Agency in establishing its position, vis-a-vis formulating plans and providing guidance to other agencies. The analysis contained herein is also felt to be important for the purpose of informing the many concerned parties of the status and results of the considerable amount of research which has been performed. The sources of information for many of these concerned parties is quite limited, and unintentional distortions often arise due to information transfer through popular reporting media. The analysis reported here has attempted to be an objective distillation of the vast amount of reviewed information into a concise account of the progress that has been made, and the remaining uncertainties associated with the complex topic of the health and environmental effects of EHV electrical power transmission.

The health and environmental aspects of EHV transmission naturally divide into two broad areas. The first comprises concern over the possible effects caused by the electric and magnetic fields in the vicinity of the line. The second area of concern is with regard to effects caused by electrical discharges from the line.

The electric and magnetic fields that exist in the vicinity of power transmission lines are well understood. Analytical techniques exist for calculating the predominant components of the fields (normally by use of computers), and commercially available measurement instrumentation is available to measure the principal fields above the ground in the region of the transmission line. The measurement instrumentation and calibration procedures are adequate to provide quite close agreement between predicted and measured field levels, if recognized precautions are observed. Existing measurement apparatus is not always adequate for use with laboratory biological experiments.

The fields that exist near the transmission line will cause voltages and currents to be induced on any conducting object that is placed in the field.

In general, the conducting objects of concern include inanimate objects such as metal components of buildings, vehicles, fences, irrigation apparatus, other utilities sharing the same right-of-way, etc.; and animate objects such as people, animals and plants. The voltage and current induced into most inanimate objects is of concern when animate object contact with these items is possible. However, the voltages and currents induced onto other utilities which may share the same right-of-way, such as telephone plant or pipelines, is also of concern from the standpoint of performance degradation that these currents and voltages may cause to the sharing utility.

Considerable measured data exist on the currents and voltages induced onto typical above ground metallic items which might be found near EHV transmission lines. Analytical techniques are also available for predicting the induced currents and voltages on these objects. Of particular importance is the current which might flow from such an object to a person who touches the object. The current which will flow to a person from such an object is generally quoted as the current which will flow if the object is shorted to ground. However, due to practical considerations, the current flow to a person may be less. Thus, the short circuit current is a worse case. Agreement between measurements and analytical predictions of the short circuit current is found to be reasonable. However, the measured values of object voltage to ground is usually significantly less than that predicted, due to practical factors that are difficult to account for in the analysis.

Contact with a charged metallic object beneath a transmission line produces both transient and steady-state current flow to a person. The transient effects are generally characterized in terms of the energy of the discharge. It is generally agreed ıat the discharge energy from objects that the public might contact beneath transmission lines is well below the level which might cause physical harm (circa 50 joules). However, many large objects might be charged to levels above the perception threshold level, typically taken as 0.1 millijoule, which could result in a startle reflex.

Grounding of stationary objects that can develop such energies is routinely employed. It has been suggested that additional quantification of human spark discharge perception threshold would be beneficial.

The steady-state current that can flow from a charged object to a person can attain hazard levels for very large objects. The power companies, as a matter of policy, provide grounds for those stationary objects which can provide short circuit to ground currents in excess of 0.5 milliamperes. This current level is below the perception threshold for nearly all people, and is also the leakage current level that common household appliances must not exceed.

Mobile objects beneath the transmission line appear to be the area of greatest concern, since they cannot be controlled as well or as easily mitigated as stationary objects. It is generally accepted that lethal currents, e.g., sufficient to cause fibrillation, cannot be obtained from the largest vehicles expected beneath transmission lines. However, the principal question with regard to vehicles appears to be: Can the current levels for large vehicles be larger than the "let-go" level, particularly for children?

Adequate data do not appear to exist for either the current level from vehicles under practical conditions, or the "let-go" threshold, to permit a realistic assessment of risk. For ideal "non-practical" conditions, large vehicles can produce more current than available let-go limits. However, the use of ideal vehicle current data and existing let-go data have both been questioned.

In addition to producing current and voltage on inanimate objects, the fields from EHV transmission lines also cause currents to flow and voltages to be developed within persons, animals and plants. The subject of the possible biological effects of these induced currents and voltages is likely the most controversial aspect of the interaction of EHV fields with life forms. The experimental procedures necessary to adequately establish the influence of such fields on life forms are highly complex. Such experiments are plagued by the problem of misinterpreting causes and effects.

The analysis that has been performed on this study has evidenced that virtually no authority in the field feels that the work in this area is complete. However, there also appears to be no widely accepted evidence that firmly establishes any deleterious effects to healthy individuals caused by such fields, at the levels which might normally be encountered.

Various experiments have provided strong evidence that some biological subjects may sense, or respond in some manner to low frequency electromagnetic fields, e.g., behavioral studies. In some cases, response was obtained at quite low field levels. Although these experiments have provided preliminary indication of response, no indication of deleterious response is evident.

There have been a number of studies that have reported the alteration of one or more monitored biological parameters as a result of subject exposure to low frequency electromagnetic fields. A significant portion of such reports have Russian or East European origin. However, the work of some Western investigators has also produced reports of biological parameter alterations. These reports cite responses that are indicative of interaction of the fields with cardiovascular or central nervous system functions or manifestations of stress on the test subject.

The work of Russian and East European investigators has been much criticized by Western investigators, due to obvious poor procedures, lack of adequate reporting of experimental details, and disagreement with similar investigations conducted in the Western world. The Western investigations that have shown positive interactions have been questioned on the basis of a variety of procedural, biological and environmental factors.

In addition to considerable disagreement existing on the interpretation and acceptance of experimental evidence, no widely accepted theory exists which might explain such interactions. It is evident that considerable work is yet required to fully understand the interaction of low frequency electromagnetic fields with life forms. However, the work which has been performed to date has not provided convincing evidence that any threat to the public health or welfare has been caused by existing exposure levels. Evidence as to what exposures might constitute such a threat appears, at this time, to be either nonexistent or not accepted by an adequate segment of the scientific community.

The electric discharges which occur along transmission lines is the second broad area which has been addressed in this analysis of information submitted in response to the Federal Register Notice. The principal discharge of concern is the production of corona along the line. The production of corona results in three side effects which have been extensively investigated. These side effects are the generation of gaseous effluents, principally ozone, the generation of audible noise, and the generation of radio frequency noise.

Corona is a phenomenon that occurs in the immediate vicinity of the transmission line conductors due to the strong electric fields that exist at the conductor surface. In addition to producing the side effects noted above, corona also causes power to be lost along the transmission line. However, the side-effect aspects of corona (principally audible noise and radio frequency interference) are sufficiently important that they, rather than the corona loss, control the design of the transmission line with respect to corona.

Corona is principally a foul weather phenomenon. That is, transmission lines are essentially corona-free in fair weather. However, it is not possible to design a practical EHV transmission line to be free of corona during foul weather.

Ozone concentrations above certain amounts are highly undesirable. In fact, National Air Quality Standards exist which limit ozone concentrations.

Ozone production from transmission lines is related to the corona loss along the line, as well as the temperature and humidity. The analytical prediction of ozone levels beneath transmission lines is generally regarded as resulting in higher levels than would be encountered in practice. The higher-than-realistic values are a result of simplifying assumptions made in the analysis. Only recently has the important "zero wind" case been analyzed.

Depending on the assumptions used in the analysis, worse-case ozone predictions in the range of an order of magnitude less than the National Primary Air Quality Standard limit are obtained. The anticipated low ozone levels at the earth's surface have been corroborated by several extensive series of field measurements. These measurement programs concluded that the transmission lines did not significantly alter the ambient ozone levels. Thus, based on the work which has been conducted, it is widely felt that ozone production by transmission lines does not pose a significant environmental concern.

Corona on EHV power transmission lines is accompanied by the production of audible noise. The highest levels of audible noise are produced during the most severe weather conditions, such as during heavy rain. Minimizing the production of audible noise is an important consideration in transmission line design. The extensive laboratory and field work that has been performed has resulted in a good understanding of the audible noise levels that will be produced from a particular transmission line design.

There are several documented guidelines and standards which have been promulgated or proposed to protect the public health and welfare from environmental audible noise. However, these guidelines are based on noise which may have considerably different characteristics than the audible noise from transmission lines. Thus, considerable disagreement exists on the applicability of such guidelines to transmission line audible noise.

Due to the correlation of transmission line audible noise with foul weather, when the ambient noise may be high, many feel that the masking aspects of the ambient noise have not been properly accounted for. Due to the foul weather considerations, most concern appears to be with regard to the noise that penetrates dwellings near the right-of-way. In addition, due to the high ambient noise within dwellings during the day time, most concern centers on the potential sleep disturbing effects of the noise. However, at this time, the sleep disturbing effects of power line audible noise have not been adequately quantified. Research is currently being conducted to provide additional quantitative information on the various unknown factors associated with transmission line audible noise and the response of people to such noise. These research efforts will hopefully result in needed basic information on the acceptable noise from transmission lines, so that meaningful guidelines can be established.

In addition to producing audible noise, corona on transmission lines also produces noise in the electromagnetic spectrum. Such noise can interfere with the reception of both radio and television signals for receivers located close to the line. The degree of reception degradation that is caused by such noise is a function of the strength of the noise relative to the strength of the desired broadcast signal at the receiver location. Thus, interference due to power line electromagnetic noise is generally noted more in rural areas, where broadcast signal strength is low.

The production of electromagnetic noise from power lines is quite well understood, and is a primary consideration in the design of new transmission lines. Somewhat less fully understood is the subjective aspect of television viewer response to such noise. Even though the influence of line design on radio noise is well understood, it is not practical to design EHV transmission lines that do not produce any electromagnetic noise. In certain locations, under foul weather conditions, radio or television interference may become apparent.

While it is not possible to eliminate the electromagnetic noise near the lines, in general, it is possible to significantly reduce the interfering effects by the application of appropriate mitigative procedures. The power companies will respond to valid interference complaints, and can, in most cases, take steps on a local basis to provide customers with adequate radio and television reception. Radio or television interference which occurs during fair weather is not normally due to transmission line corona, but to sparking at hardware components. Steps can readily be taken by the power companies to eliminate the sources of such interference, if they are made aware that interference is occurring.

From the above paragraphs, it is seen that the available information, in general, provides a good knowledge base on the various physical phenomena that result from the transmission of electrical power by EHV lines. It also appears to be reasonably well established that the normal environment produced by such transmission lines does not produce any significant health or environmental risks. However, there appear to be areas yet remaining, where adequate knowledge does not exist and where additional research is yet required.

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1. INTRODUCTION

1.1 Background

Private citizens, public interest groups, and state agencies have expressed concern about potential adverse effects of Extra-High-Voltage (EHV) transmission lines. In response to this interest, the U.S. Environmental Protection Agency published a notice* in the Federal Register (FRL 312-2), asking for data and information on the health and environmental effects of 60 Hz transmission lines energized at 700 kV or higher. The intent of the notice was to develop information that would (1) help to categorize potential adverse effects, and (2) assist the Agency to determine whether there was a need to provide guidance to Federal agencies or to formulate plans for future regulatory action to protect the public health and welfare.

Over fifty (50) replies, totaling over 6,000 pages, were received in response to the Agency's request distributed approximately as follows: electric utility or organization, fourteen (14); Federal agencies, eight (8); citizen or citizen's group, six (6); state agencies, five (5); consulting firms, four (4); equipment manufacturer, four (4); city or county planning agency, three (3); university, three (3); railroad, pipeline, and professional society, one (1) each. Appendix A, entitled "Respondents to FRL 312-2," provides a list of the respondents together with a brief description of the response, and Appendix B presents a list of the technical information submitted by these respondents with a key to the respondent submitting each technical item.

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*Federal Register, 40(53):12312, 18 March 1975.

1.2 Scope and Organization of Report

After receipt of the submitted information, the Environmental Protection Agency performed a preliminary analysis of the material, as well as other information available, and tentatively concluded that no acute detrimental health or environmental effects had been identified. However, an in-depth analysis of the material was needed to determine if there were potential subtle problems and to determine if areas of concern had been adequately investigated. This report is the result of the in-depth analysis of the submitted material.

Two principal areas have been treated: first, the effects of electric and magnetic fields, and second, the effects of electric discharges. The first area is treated in Section 2 and the second is treated in Section 3.

Section 2 of this report presents an analysis of information concerning the electric and magnetic fields produced by Extra-High-Voltage (EHV) power transmission lines. Included is a review of the methods used to calculate and measure the fields; a quantitative description of the voltages and currents induced on objects by the fields; a discussion of the effects of such current and voltage on humans who may come into contact with these objects; and a discussion of the effects of transmission line fields on living organisms.

Section 3 of this report presents an analysis of information concerning the effects of electric discharges which accompany the transmission of power by EHV lines. Included is a discussion of the discharge phenomenon, principally corona, and the various side effects of concern resulting from the corona process. The side effects of concern include the production of ozone and other gaseous effluents; the generation of audible noise; and the production of electromagnetic noise in the radio frequency spectrum.

Since the purpose of the analysis was to assess the material submitted in response to the Federal Register Notice FRL 312-2, the discussions that are presented strongly reflect this material. However, in the period of time that has passed since the submittal of data in response to the Federal Register Notice, additional research information has become available. In addition, other major analyses of information in specific topical areas have been published. Although the scope of the effort did not include the searching-out of additional information, such information, where known to exist, has been used to supplement the submitted technical material, where appropriate.

Some responses that were received noted individual or group concern over factors associated with the disruption of the environment by the installation, rather than the operation, of transmission lines. Environmental aspects associated with factors such as visual impact, geology and hydrology, land use, vegetation and wildlife management, and others that relate to the physical presence of the line, or the procedures necessary to install the line, are considered beyond the scope of this analysis. An excellent discussion of many of these factors is presented by Cahn Engineers, Inc., 1974.

1.3 Technical Depth

The material reviewed in the preparation of this report ranged from highly technical theoretical treatises to personal views of the layman. It is anticipated that these same people may read this report. Therefore, an attempt has been made to present the material of this document in a manner which adequately represents the scientific results, while being readable by the layman.

However, the layman may find the reading somewhat difficult in places. Some equations have been presented for completeness, but this has been kept to a minimum. Since the document deals extensively with the quantification of physical and electrical parameters associated with the line, certain terms unfamiliar to the layman are necessary. An effort has been made to present these terms in an understandable manner. For those who desire more technical depth or detail than is presented here, they are referred to the referenced technical material used in developing this report.

1.4 EHV Transmission

Extra-High-Voltage power transmission is the term generally used to denote power transmission lines in the range of voltages between 230 and 765 kV (kV denotes thousands of volts), McLoughlin, 1975. 345 kV transmission lines have been in service since the 1950's, with in excess of 30,000 circuit miles in service as of 1976. The first 765 kV lines were placed in service in the United States and Canada in the late 1960's. The power industry is actively working on solving problems associated with even higher voltage transmission lines, above 800 kV, which are termed Ultra-High-Voltage (UHV) lines.

Concern over the possible adverse effects of EHV transmission, particularly at the upper end of the voltage range, has been reflected by both the public and the power industry. This concern is evidenced by the considerable amount of research that has been conducted into possible health and environmental effects of such lines. Due to increased interest and the desire to extend the voltages yet higher, it is likely that the research will continue.

For those not directly involved with the power industry, it is natural to question the reason why the power industry desires to increase the operating voltage, when there are problems involved in such a move. Harvey, et al., 1977, summarizes the basic move to higher transmission voltages by noting that perhaps the most obvious reason is the reduced amount of land required for right-of-way purposes. They state that a single 765 kV line can transmit an amount of power equivalent to four or five 345 kV lines, each which can transmit an amount of power equivalent to that carried by five or six 138 kV lines.

Young, F. S., 1976, develops the concept of an efficiency index for transmission lines which takes into account the right-of-way width and tower height as a three dimensional power corridor. He notes that as population density increases, the availability of corridors for transmission lines decreases, thus necessitating the most efficient use of acquired corridors. Using this efficiency index, Young provides examples that show an increased power corridor efficiency (decreased corridor volume for the same load) as the line voltage is increased, at least up to the 1200 kV range. He further notes that at this time there are no economically competitive alternatives to overhead ac transmission.

Some, such as Young, L. B., 1973, challenge that adequate research has not been conducted for the purpose of developing economically attractive alternates to overhead transmission, thus making the power industry dependent on the use of such lines. These topics, dealing with alternatives to overhead transmission of power at 60 Hz voltages in the range of 700 kV, while important, are considered beyond the scope of this document. These topics will therefore not be further treated.

2.0 ELECTRIC AND MAGNETIC FIELDS

Power transmission lines produce both electric and magnetic fields in their near vicinity. These fields can be calculated and measured. The fields couple to objects which may be located near the transmission lines, causing current to flow and voltages to appear on the objects. The coupled objects can be either animate, such as people, animals or plants, or inanimate such as fences, vehicles or other metallic items.

This section quantitatively discusses the procedures used to calculate the fields from transmission lines and the instrumentation used to measure these fields. The current and voltage that can be induced on various objects is also discussed. The current and voltage induced on inanimate objects can cause current to flow to a person that touches the object. In addition, the coupling of the fields to living organisms has caused considerable concern and has resulted in significant research efforts. The coupling of fields to living organisms is discussed in terms of the research that has been conducted and the problems associated with the conduct of such research.

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2.1 Quantitative Description of Transmission Line Fields

The voltage which appears on transmission lines, and the current that flows in the lines, causes electric and magnetic fields to be produced in their vicinity. The charge which appears on the transmission lines causes the electric field. The current flowing in the transmission line, causes a magnetic field to be established in the region about the line.

In all analyses that are performed, the electric and magnetic fields from transmission lines are considered as separate entities. It is common engineering practice to consider separately the electric and magnetic fields, when the distances or object sizes are small compared to a wavelength. At the power line frequency of 60 Hz, a wavelength is 5×10^6 meters. Thus, the distances and object sizes of concern are a minute fraction of a wavelength.

The electric fields are discussed in terms of the electric field intensity, or spatial voltage gradient. The units used to express the electric field are volts per meter (V/m) or where high fields are involved, kilovolts per meter (kV/m). The magnetic fields are discussed in terms of the magnetic flux density, usually stated in the familiar and still widely used CGS unit, Gauss; however, the MKS units are also often employed. In the MKS units, the magnetic flux density is expressed in terms of Webers/square meter or Teslas. To convert Gauss to Teslas, multiply Gauss by 10^{-4}.

The theory which permits either the electric or magnetic field to be determined in the vicinity of a transmission line is well established. The material submitted in response to the EPA Federal Register Notice, as well as more recent testing and analysis reported by the U.S. Environmental Protection Agency, 1977, adequately demonstrate that: highly accurate prediction of the fields can be made; instrumentation is available to measure these fields; and a good correlation exists between the measured and calculated values for fields in a plane normal to the transmission line.

2.1.1 Analytical Description

2.1.1.1 Electric Field

The starting point for determining the electric field in space resulting from a transmission line, is generally the relationship between charge, capacitance and voltage. The relationship among these quantities is expressed in matrix notation as [Q] = [C][V], where [C] is a capacitance coefficient matrix, and [V] is the voltage impressed upon the conductors in volts. The analysis normally assumes that the conductors are infinitely long line charges and the earth is assumed to be a highly conductive, or ideal plane. The analysis makes use of symmetry, and account for the ground plane is made by the method of images.

For a three phase transmission line, the voltage impressed on the three conductors are separated in time phase, that is, the voltage on the three conductors differ in phase by 120° from each other. Given the conductor voltages and the capacitive coupling coefficients which are determined by the geometry of the configuration, the conductor charge can be determined by the matrix relationship. Once the conductor charges are known, the electric field at any point in space can be determined by the relationship $E = Q/2\pi\varepsilon r$. This relationship gives the field from any of the charged conductors or their images. The total field is obtained by the superposition of the fields due to each conductor and image.

This basic procedure, or variations in which the field is determined from the gradient of the electric space potential, is described in varying degrees of detail in the material received in response to the Federal Register Notice. Variations in analytical procedure also occur in the manner in which bundled conductors for the transmission line are analyzed. One approach outlined by Balderston and Zaffanella, and also in the Transmission Line Reference Book, 345 kV and Above, 1975, is to analyze the bundled conductor as an equivalent single conductor having an equivalent diameter d_{eq} given by

$$d_{eq} = D\left(\frac{nd}{D}\right)^{1/n}$$

where

D is the bundle overall diameter

n is the number of subconductors, and

d is the diameter of the subconductors.

This expression holds for the case of regular bundles. When the bundle is not regular, expressions such as provided in Mathews, H. G., 1975, can be used to determine the equivalent single conductor diameter. Alternately, the charge and field due to each subconductor can be determined. The use of this procedure for analyzing bundled conductors is indicated in the submittal of "Analytical and Computer Analyses" by Shih, 1974. While the procedures and analyses used to calculate the electric fields due to transmission lines are based on sound and well-accepted electrical engineering principles, the steps involved in such calculations are long and in general require the use of computers.

The electric field at a point in space is a vector quantity. In quantifying the fields from transmission lines, it is common practice to express the field in terms of its rectangular coordinates at the point of interest. Due to the assumptions of an ideal ground which is used in the analyses, only two components of the electric field result from the analysis. Both these components lie in a plane that is normal to the transmission line. The field is generally represented by a horizontal component which is parallel to the ground, and a vertical component. These two components of the electric field are not in time phase, for a three phase system. Thus, the total electric field vector rotates in the plane at a

60 Hz rate, and the tip of the vector traces out an ellipse. As a near ground observation point moves further from the transmission line, the horizontal component of the electric field normal to the transmission line becomes quite small with respect to the vertical component. Thus, the vertical component dominates and is generally the field component which is normally discussed.

The electric field analysis discussed above does not consider the finite conductivity of the ground. However, neglecting this finite conductivity is adequate for prediction of the dominant components of the electric field in air above the ground. Due to the finite conductivity of the ground, electric fields exist in the earth beneath power transmission lines. The direction of the electric field vector in the ground, is parallel to the current flow in the transmission line. The horizontal electric fields in the ground are developed from currents flowing in that ground. These currents arise from three sources: 1) unbalanced, harmonic and fault currents through the power system earth counterpoise; 2) displacement currents collected by the ground from the time varying electric field; and 3) eddy currents induced in the soil by the time varying magnetic field.

The methods for predicting these ground potentials for idealized distributions of ground conductivity and permittivity were developed in the late 1920's and over the 1930's. These developments are summarized by Sunde, 1968. The practical thrust of this effort was to investigate grounding related to inductive interference as might be experienced by a telephone line, from fields generated by power lines. Also of interest is the computation of induced currents and voltages on pipelines. Simplified methods for realistic situations to calculate field intensities and currents in earth, as related to overhead transmission lines, remains to be developed for handbook application.

Numerous submittals in response to the Federal Register Notice provided theoretical curves of the electric field from EHV transmission lines. Included is Shah, 1975; Matthews, 1975; Shih, 1974; Barnes, 1974; Reiner, 1971; Lyskov, 1975; and the response to the EPA request prepared by the Detroit Edison Company, 1975. Figure 2.1 shows a re-plot of data supplied by the Detroit Edison Company and compares this with the theoretical curve provided in the Russian paper by Lyskov, 1975. Detroit Edison compared the results of their computer program to a curve presented by Dino and Zaffanella in the Transmission Line Reference Book, 345 kV and Above. These two curves were calculated for a 1050 kV single circuit transmission line, having a phase-to-phase separation of 15.1 meters and a height above ground of 15.1 meters. It is seen that the results of these two calculations are very close. Shown for comparison in Figure 2.1 is also a curve re-plotted from Lyskov for a 1150 kV line. The Russian curve indicates slightly higher maximum electric field strength than the American example; however, this is probably due to the greater phase separation used in the example by Lyskov.

The use of the above described procedures for determining the electric field, in general requires the use of digital computers to perform the calculations. However, Balderston and Zaffanella, 1975, present a procedure using generalized adimensional curves to determine the maximum voltage gradient at ground level due to practical flat-line configurations. The use of the procedures outlined in this paper allows rapid determination of the maximum electric field, which occurs slightly outside of the outer phase, for this line configuration. Balderston and Zaffanella also present a table, repeated here as Table 2.1, which shows the maximum gradients at ground level for typical EHV transmission lines in the United States.

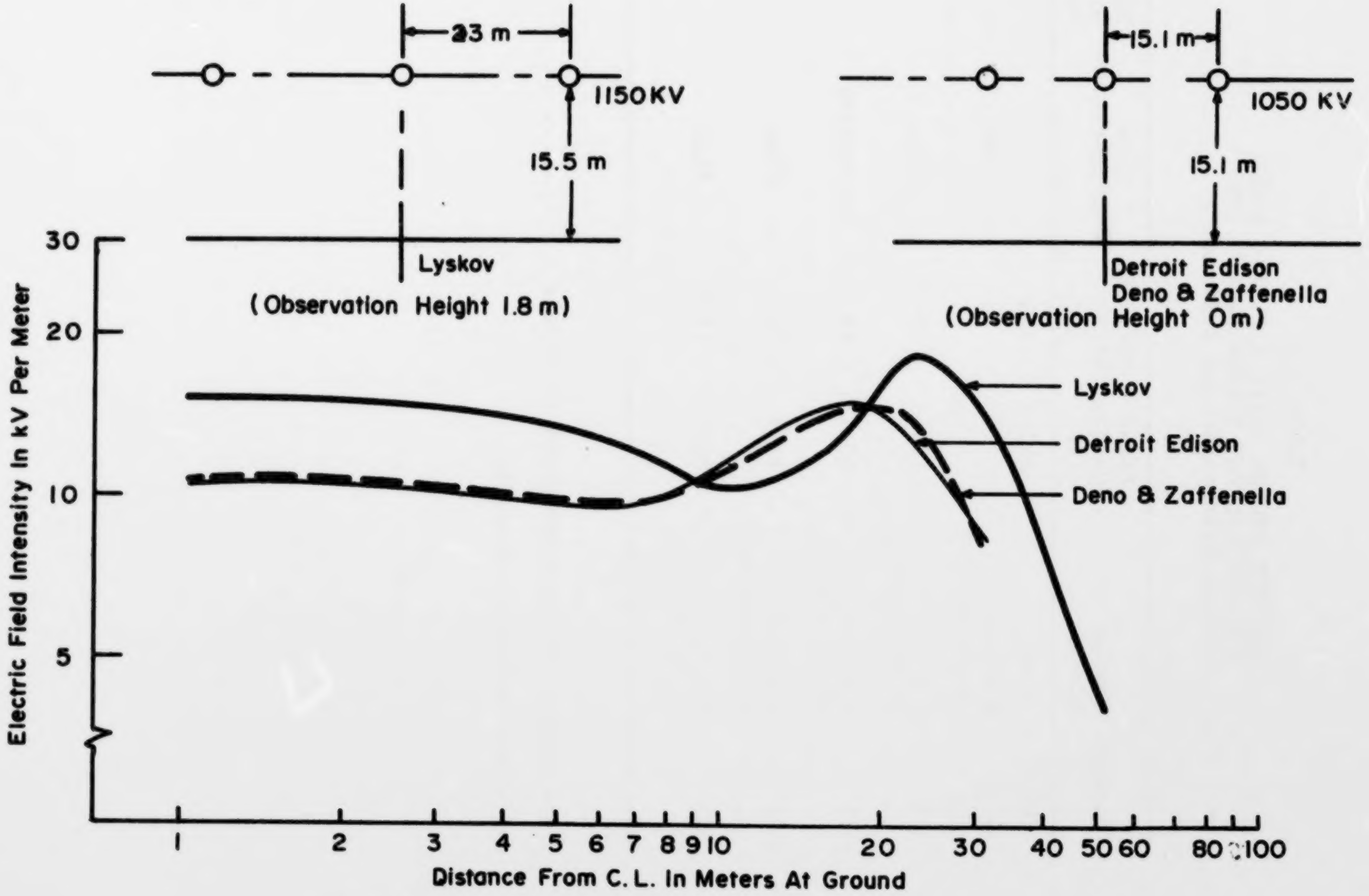

Fig. 2.1 COMPARISON OF CALCULATED VERTICAL ELECTRIC FIELD

Table 2.1

MAXIMUM GROUND LEVEL ELECTRIC FIELD FOR TYPICAL EHV TRANSMISSION LINES
(from Balderston and Zaffanella)

Voltage	Bundle* (n x d)	Phase Spacing (s)	Minimum Height (h)	Line Configuration	Maximum Ground Gradient
(kV)	(cm)	(m)	(m)		(kV/m)
345	2 x 3.3 46 cm spacing	7.3	9.7	Flat	5.2
525	3 x 3.3 46 cm spacing	10.1	10.7	Flat	8.8
525	3 x 3.3 46 cm spacing	10.1	10.7	Triangular	6.8
765	4 x 3.5 46 cm spacing	13.7	13.7	Flat	10.3
765	4 x 4.1 61 cm spacing	13.7	16.5	Flat	8.3

*n = number of sub-conductors in bundle

d = sub-conductor diameter.

2.1.1.2 Magnetic Field

The currents flowing in the conductors of the transmission line generate a magnetic field. As in the case of the electric field, a three phase transmission line produces a magnetic field at some distance from the line that rotates in space at a 60 Hz rate. Again, as in the case of the electric field, the magnetic field vector lies in a plane normal to the transmission line and the tip of the magnetic field vector traces out an ellipse in this plane. The magnetic field flux density, due to the current flowing in an infinitely long current carrying conductor is given by

$$\bar{B} = \frac{\mu_o I}{2\pi r} \bar{\theta} \text{ webers/m}^2$$

where

μ is the permeability of the medium

I is the current in the conductor

r is the radial distance from the center of the conductor

$\bar{\theta}$ is a unit vector which indicates the direction of the magnetic field

Again, as in the case for electric field, it is common practice to express the magnetic field as two vectors, one which is parallel to the ground plane. The magnetic field component from each current carrying conductor is found and the total magnetic field is obtained by the principle of superposition.

For bundled configurations, an equivalent conductor is assumed to be located at the center of the bundle. This is valid since the conductor spacing in a bundle is much smaller than the conductor to observation point spacing, for observation points of concern. Generalized expressions for the two components of magnetic flux density as given by Diplacido, 1975, are

$$\bar{B}_{x(RMS)} = \frac{\mu_o}{2\pi} \sum_{i=1}^{n} \frac{\bar{I}_i \cos \alpha_i}{[(x_p-x_i)^2 + (y_p-y_i)^2]^{\frac{1}{2}}}$$

$$\bar{B}_{y(RMS)} = \frac{\mu_o}{2\pi} \sum_{i=1}^{n} \frac{\bar{I}_i \cos \alpha_i}{[(x_p-x_i)^2 + (y_p-y_i)^2]^{\frac{1}{2}}}$$

where

$\bar{B}_x$ is the horizontal component of flux density

$\bar{B}_y$ is the vertical component of flux density

x_p and y_p are respectively the horizontal and vertical coordinates of the observation point

x_i and y_i are respectively the horizontal and vertical coordinates of the ith current carrying conductor

$\bar{I}_i$ is the phasor current, i.e., taking account for phase, which flows in the ith conductor, and

$\alpha_i = \pi/2 + \arctan(y_p-y_i)/(x_p-x_i)$.

The normal application of the analytical techniques for determining the magnetic field is to determine the magnetic field as a function of distance transverse to the transmission line at nominally ground level. As in the case of the electric field calculations, the analysis is usually performed by use of a computer. Shown in Figure 2.2 is the maximum magnetic flux density in Gauss as presented in DiPlacido, 1975, as a function of the lateral distance from the center line of the transmission line. For this plot the phase-to-phase separation was 45 feet and the phase current was 1000 A. The different curves presented are for different vertical distances between the phase conductor height and the height at which the magnetic flux density is being sampled. If the sampling of the magnetic field is considered to be at ground level, the heights shown for the different curves then correspond to the height of the phase conductors of the transmission lines.

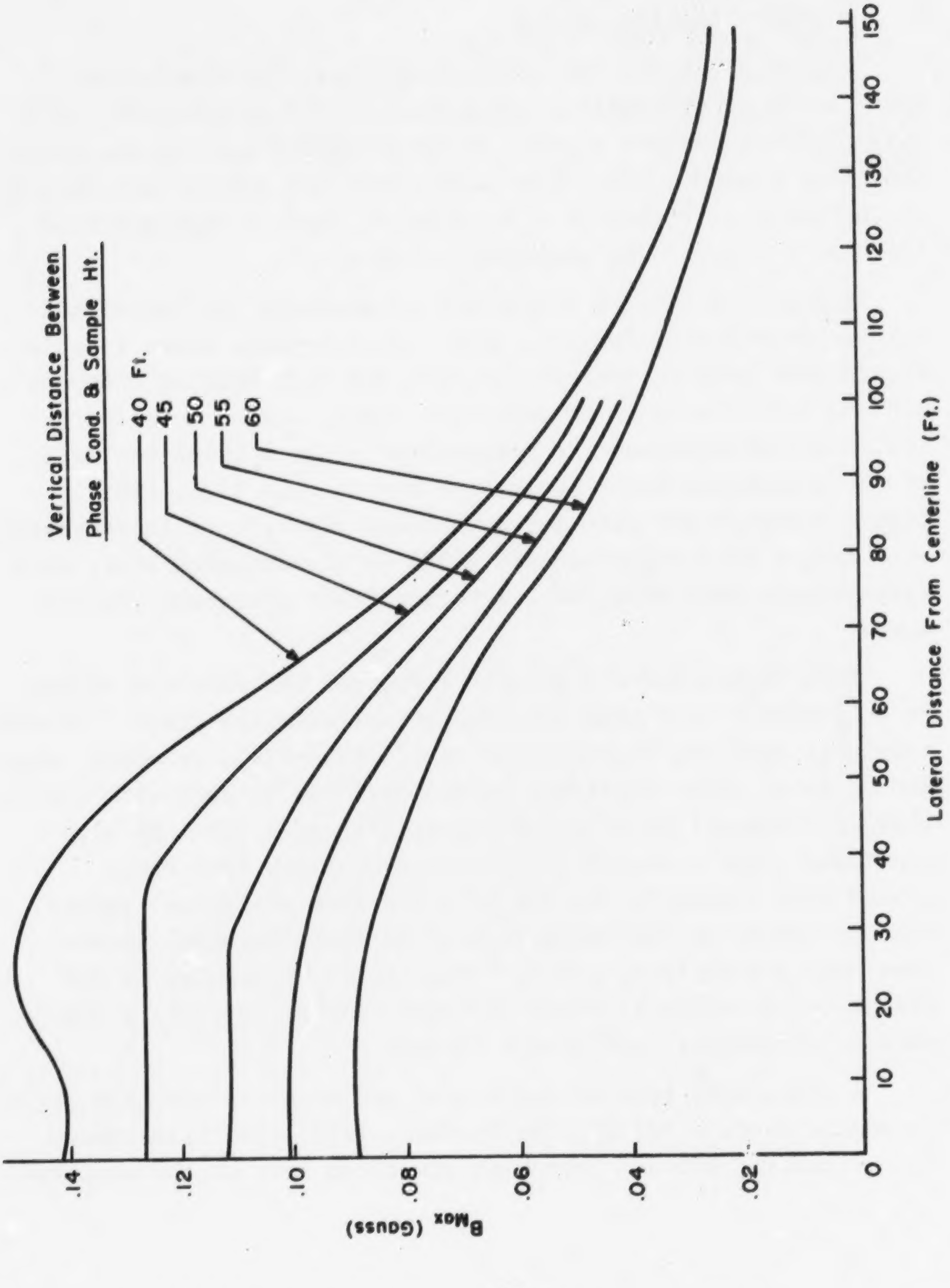

Fig. 2.2 MAXIMUM MAGNETIC FLUX DENSITY FROM TRANSMISSION LINE - THEORETICAL CURVE (FROM DI PLACIDO, 1975)

2.1.2 Measured Values

2.1.2.1 Electric Field

Figure 2.3 shows the vertical electric field measured under a 765 kV transmission line as reported by Zalewski, 1975. This figure shows the results of measurements made at two heights above the ground. The figure also shows the symmetrical nature of the electric fields as a function of lateral distance from the center line of the transmission line.

Figure 2.4 shows a comparison of measured and calculated values presented by Bracken, 1975. Measurements shown in this figure were made in conjunction with the IEEE Working Group on E/S and E/M effects of transmission lines, during an electrostatic and electromagnetic measurement program which was held at the Bonneville Power Administration in July 1974. This figure compares the calculated vertical electric field strength, at a height of 1 meter beneath a 525 kV transmission line, with measurements made with three separate field measuring instruments.

This figure shows a general trend for the measured values to be somewhat less than the theoretical electric field. Bracken concludes that the measurements of electric field strength, near ground level under realistic conditions, can be made with available instrumentation with reproducibility of ± 10%. He also concludes, that measured field strength values over rough ground have common variations of ± 10% from analytical values that are based on the assumption of infinite parallel conductors over a flat ideal ground. Also noted by Bracken is the effect on the electric field strength measurement due to vegetation, structures, and ground surface.

A comparison between calculated and measured electric field strengths under a 525 kV line by Shah, 1975, also illustrates the perturbing effects that high grass can have on the measured

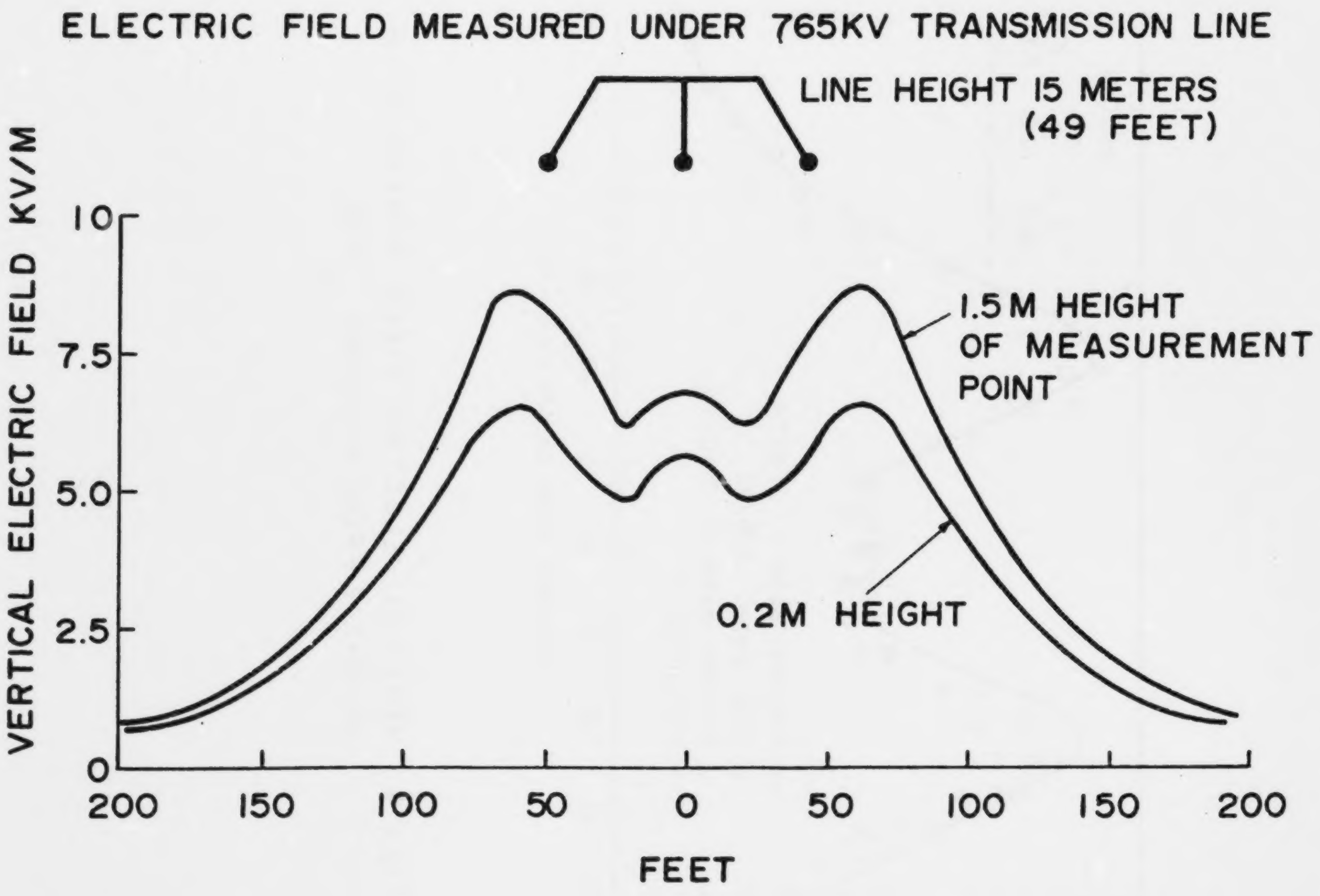
ELECTRIC FIELD MEASURED UNDER 765KV TRANSMISSION LINE
LINE HEIGHT 15 METERS
(49 FEET)
VERTICAL ELECTRIC FIELD KV/M
10
7.5
5.0
2.5
0
1.5M HEIGHT
OF MEASUREMENT
POINT
0.2M HEIGHT
200
150
100
50
0
50
100
150
200
FEET

Fig. 2.3

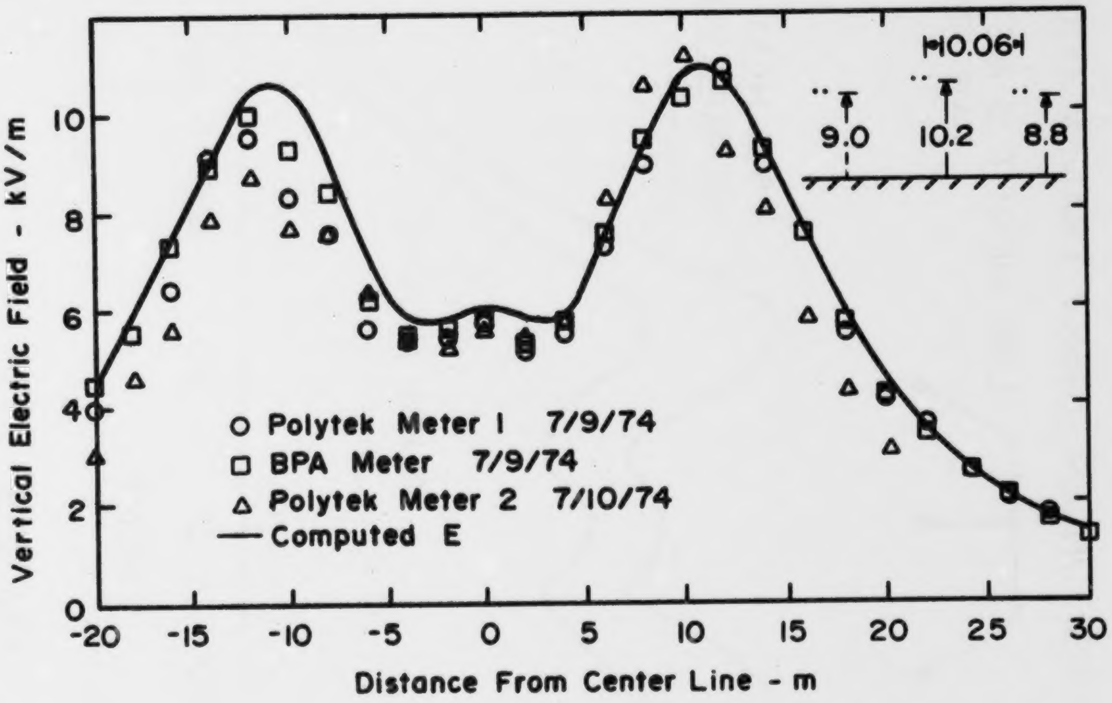

Fig. 2.4 VERTICAL ELECTRIC FIELD STRENGTH 1m HEIGHT (FROM BRACKEN , 1975)

values of electric field. Data presented by Shah show that in regions where high grass occurred, the measured values could be up to 20% less than those calculated. Pokorny, 1973, also notes a considerable reduction in field intensity in the presence of trees; he notes that selective planting of medium sized trees might be useful for reducing the electric field in some circumstances.

The electric field calculations and measurements that have been shown are in general near the mid-span of transmission lines, that is, midway between supporting towers. This region is, in general, where the transmission line conductors are the closest to the ground. As the point of observation is moved away from mid-span toward one of the towers, the electric field is substantially reduced, due to the increasing height of the conductors above ground and the presence of the tower. Figure 2.5 shows measurements reported by Zalewski, 1975, which were made under the center phase of a 765 kV line, as a function of the distance from a tower. It is seen that a significant decrease in field level occurs as the tower is approached.

2.1.2.2 Magnetic Field

The 60 Hz magnetic fields measured under a 765 kV and a 345 kV line at a height of approximately 1.5 meters above the ground are shown in Figures 2.6 and 2.7, taken from Zalewski, 1975. In these figures, the "vert" refers to the vertical magnetic field component; "B horz. per." refers to the magnetic field component perpendicular to the transmission line; and "B horz. par." is the horizontal magnetic field component which is parallel to the direction of the transmission line.

The line current shown in Figure 2.6 does not represent a full load current. This current would normally be in the 1000 to 2000 ampere range and could be higher. For these currents, and with the line height decreased to 13.7 meters, the approximate

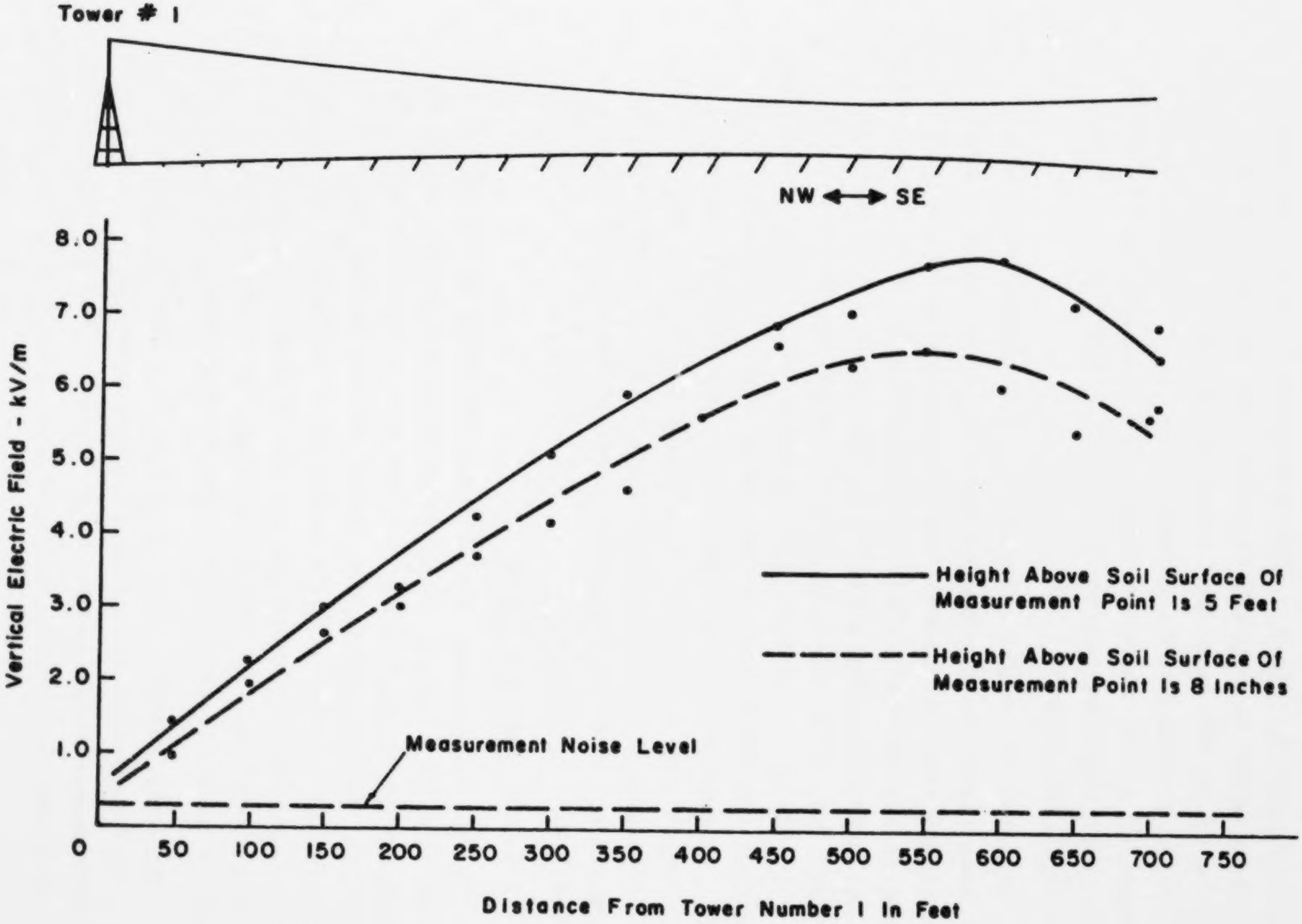

Fig. 2.5 VERTICAL E FIELD UNDER CENTER PHASE OF 765 kV LINE

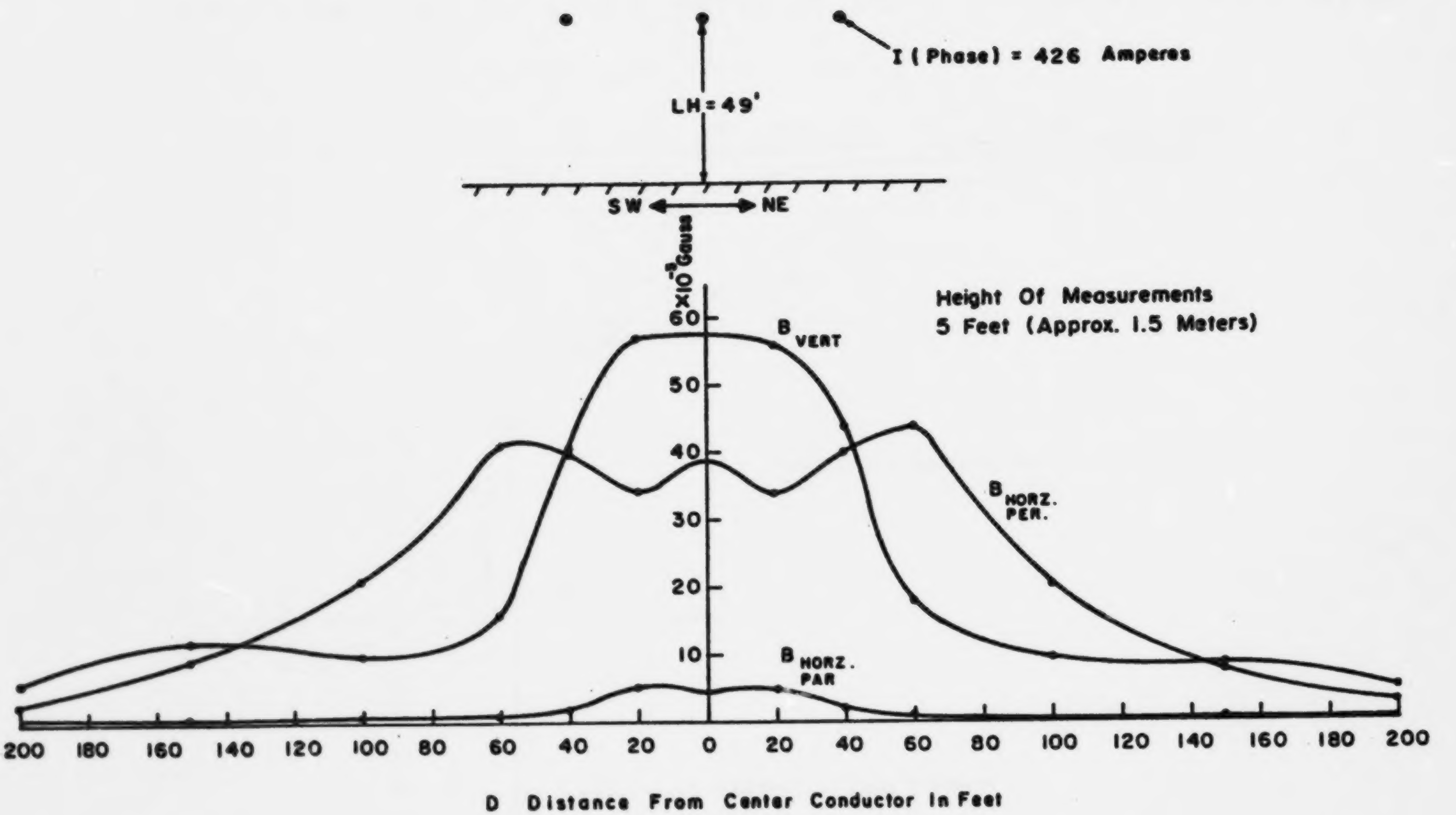

Fig.2.6 PROFILE OF THREE MAGNETIC FIELD COMPONENTS UNDER A 765 KV LINE

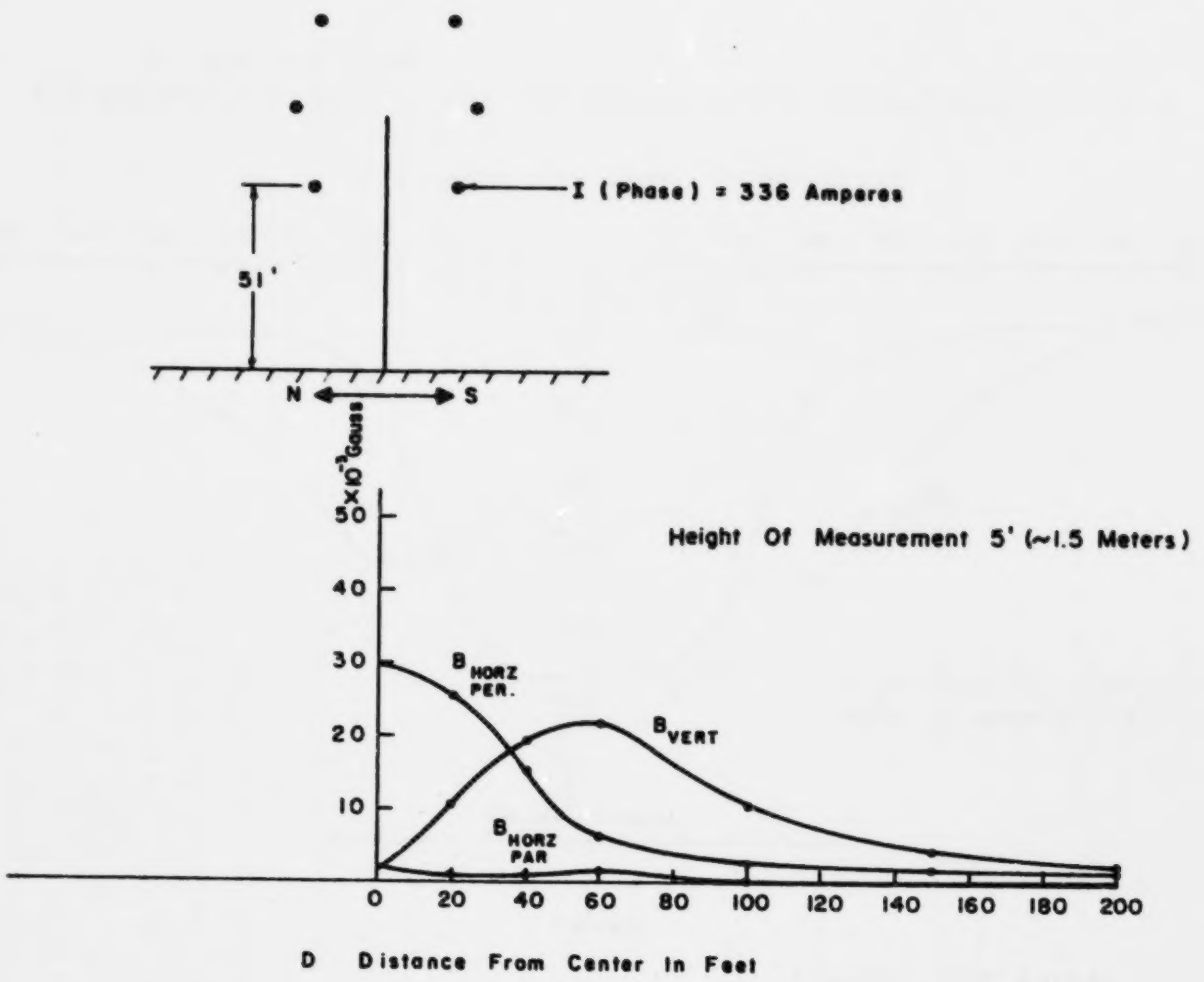

Fig. 2.7 PROFILE OF THREE MAGNETIC FIELD COMPONENTS UNDER 345 kV DOUBLE CIRCUIT BRANCH LINE

magnetic field strength under the center phase of the 765 kV line is shown in Table 2.2.

The line height of 13.7 meters is the height at the point where the line sags closest to the ground. Sixty Hertz magnetic fields of approximately one-third Gauss can be produced at ground level.

2.1.3 Instrumentation and Calibration

There are several instruments that are used for the purpose of measuring electric fields beneath transmission lines that were cited in the material received in response to the Federal Register Notice. Two of these, the Polytek and Monroe meters are commercially available in the United States. Others including the IITRI, BPA, and Miller meters have been described in the open literature or reports. One of the earliest reports on the subject of measuring the unperturbed electric field due to 60 Hz transmission lines, was a paper by Miller, 1967, who described both a grounded gradient meter and a free body meter.

2.1.3.1 Electric Field Instrumentation, Theory of Operation

There are two basic approaches to measuring 60 Hz or ELF electric fields. The first is with a free body meter, which measures the 60 Hz fields at points remote from the ground. The second type is the ground-reference type meter which measures the current to ground that is collected by a metallic surface. The theory of operation of both these classes of field measuring techniques is closely related. The free body type of field sensor is, in general, made by using a hollow metallic shell. The metallic shell is split in half and the two halves are insulated from each other. The plane of insulation is oriented to be normal to the electric field vector for maximum sensitivity.

The analysis of the field sensor proceeds by considering the displacement current density intercepted by one-half of

Table 2.2

APPROXIMATE MAGNETIC FIELD UNDER CENTER PHASE OF 765 kV LINE

Line Height - 45 Feet (13.7 Meters)

Height of Measurement Above Ground - 1.5 Meters (5 Feet)

Current in One Phase of 765 kV Line	Magnetic Field Strength
1000 Amperes	0.155 Gauss
2000 Amperes	0.310 Gauss

the sensor. The displacement current density is related to the charge induced on the surface of the sensor by the relationship

$$Q = \int_{s/2} \bar{D} \cdot dA = \varepsilon \int_{s/2} \bar{E} \cdot dA$$

Since the displacement density $\bar{D}$ is related to the electric field intensity by the free space permittivity ε, as shown in the above equation, the charge induced on the surface of the sensor is directly related to the electric field. The total charge induced is a function of the geometry and surface area as accounted for by the integral. For simple shapes such as a sphere, as is employed in the IITRI probe, the charge in terms of the electric field can be readily determined analytically by the above expression.

If an electrical connection is made between the two halves of the probe, the charge indicated above will transfer between the two halves at the frequency of the applied electric field. The current which flows between the two halves of the probe is the time derivative of the charge. Thus, by connecting the two halves of the probe through a current sensing element, a current which is proportional to the electric field will be sensed. Alternately, the voltage induced across the two halves of the probe, which is also proportional to the electric field, can be measured.

The theory of operation for the ground-reference type meter is quite similar; however, the geometry of the sensor is usually different. For the ground-reference type electric field sensor, a reference plate, which can either be circular or rectangular, is generally placed on, and grounded to, the earth. A second flat plate is placed a small distance above the grounded plate and insulated from it, thus in effect forming a parallel plate capacitor. Again, the charge induced on the upper plate is given by the expression above. Connecting the two plates by a current sensing element causes the charge induced on the upper plate to flow through the current sensing element to ground at the frequency of the applied field.

For minimal edge-effect field disturbance, a guard ring is generally placed around the upper plate. When this is done, the area to be used in the above expression for charge is, to a high degree of accuracy, equal to the physical area of the upper plate. For a well designed ground-reference voltage gradient sensor, as described by Dino and Zaffanella in Chapter 8 of the Transmission Line Reference Book, 345 kV and Above, quite accurate measurement of the displacement current, or equivalently the electric field, at ground level can be made.

2.1.3.2 Electric Field Meter Calibration

There are two general procedures that are widely used to calibrate electric field meters or probes, as described by the IEEE Working Group on E/S and E/M, 1977. The first method used to calibrate electric field probes, is to establish a known level of electric field between two parallel plates. The meter to be calibrated is inserted between the plates, and its reading compared to the theoretical field at that location. For parallel plates that are infinite in size, the electric field between the plates is uniform and is identically equal to the voltage applied across the plates divided by the separation between the plates. Thus, for the infinite plate situation, if 1000 volts are applied from plate to plate, and the plate separation is one meter, the electric field intensity between the plates is 1000 volts/meter.

In the practical case, plates which are infinite in extent are not available, thus it is important to determine the deviation from the ideal field value which is due to the use of plates of finite extent. The IEEE publication cited above presents curves by Thatcher, 1974, which show the deviation from the ideal field caused by the finite extent of the parallel plate structure. The curves are reproduced here as Figure 2.8. The curves show the field relative to the field for infinite plates, E_0, as a function of the distance x from the edge of the plate, normalized by the plate separation t. There are two curves, one for the field at the surface of either plate, the other curve for the field at the mid-plane between the two plates. These curves can be used to assess the required plate size for calibrating electric field probes.

The above field characterization for finite sized plates does not take into account the coupling to nearby objects, for example, to the walls of a room in which the calibrating structure is to be placed. To minimize field distortion due to nearby object coupling, field grading rings are generally employed; and the plates are fed in a bipolar manner, that is, by use of a center tap to ground transformer. Normally, four or more guard rings, which are wires in the shape of the plate periphery, are uniformly separated over the plate spacing. The guard rings are connected by resistors, such that the voltage at the guard ring position is forced to the desired equipotential.

Electric field meters are also calibrated by use of a carefully designed ground-reference voltage gradient sensor, employing a suitable guard ring. As discussed above, the ground-reference field sensor can be made to determine the displacement currents to ground very accurately by controlling the dimensions of the sensor. Thus, such a sensor can be used to determine the ground level electric field beneath a transmission line. A free body electric field meter that is to be calibrated, can then be positioned in the known field, above the ground-reference sensor. Normally, the free body field meter or sensor is calibrated at a height of one meter above the ground-reference sensor.

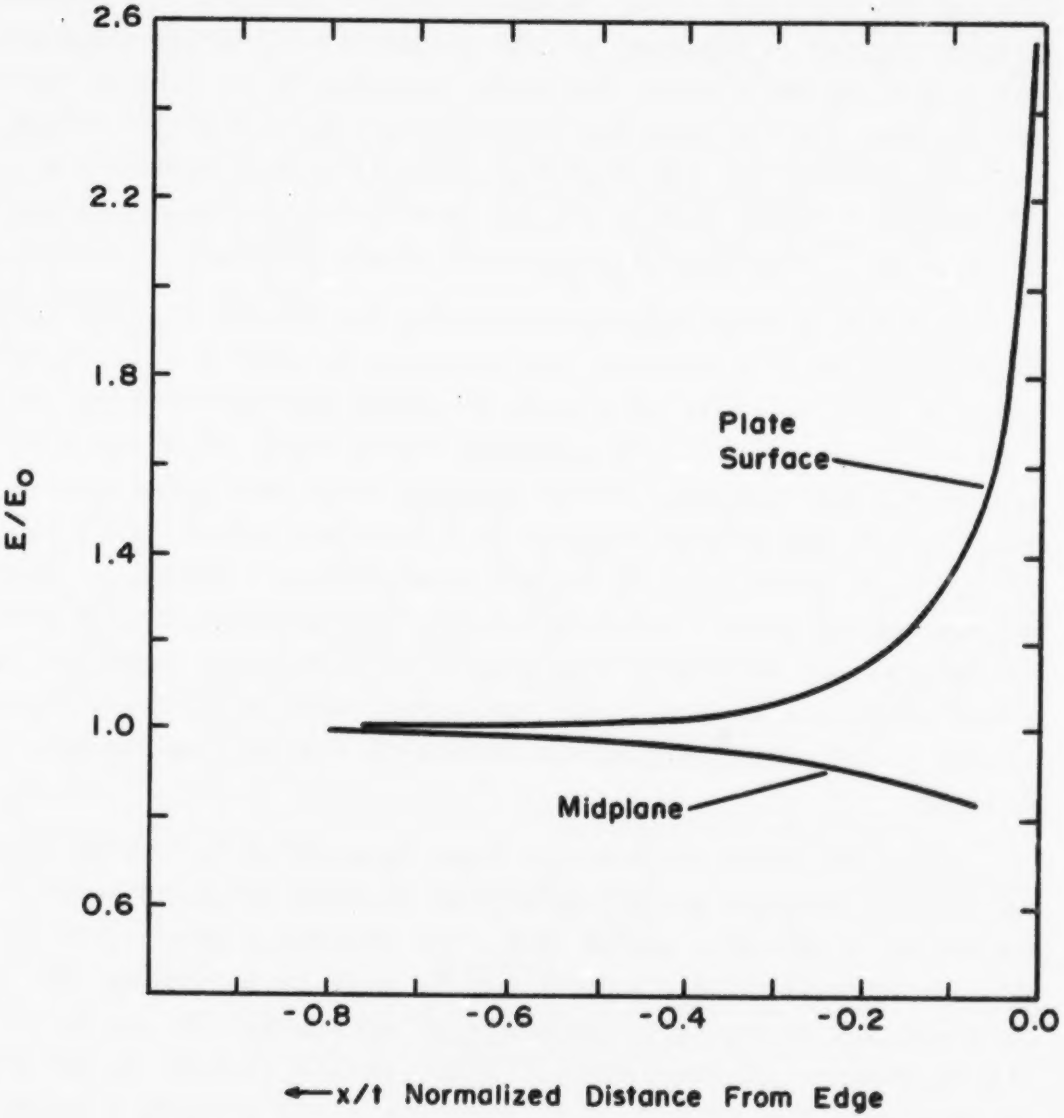

Fig. 2.8 NORMALIZED FIELD FOR FINITE PLATES (FROM IEEE...1977)

The IEEE suggests that if electric field intensity meters produce readings which are in excess of ± 5% of the field in the calibrator, the meter should be considered as inaccurate. They also suggest that the practical accuracy of outdoor measurements, using commercially available free body meters is near 10%.

Sources of error for practical measurements, identified by the IEEE, include the difficulty in positioning the meter, reading errors, handle leakage in some cases, temperature effects, observer proximity effects, and difficulty in defining the geometry of the boundary conditions. In order to minimize the various errors associated with the practical use of electric field meters, the IEEE suggests that the electric field under transmission lines should be measured at a height of 1 meter above the ground level. The meter should be equipped with an insulating handle longer than 2 meters, and the distance between the field meter and a standing operator should be at least 2.5 meters to reduce observer proximity-effect errors. Under these conditions, the observer proximity-effect error should be between 1.5 and 3%. A 5% proximity effect-error occurs when the observer distance is between 1.5 meters and 2.1 meters away from the meter.

Data supplied by the Consumer's Power Company, in response to the Federal Register Notice, provided information on the temperature sensitivity of one commercially available electric field meter, the Polytek FBM100. The Consumer's Power Company tests showed that the meter that they used was within ± 5% accuracy as specified by the manufacturer. However, their temperature sensitivity test showed an error which ranged from 4% at 74°F to 16% at 0°F. Based on these results, Consumer's Power Company makes most measurements at temperatures above 60°F.

In order to compare the results of tests performed by different investigators, a uniform procedure for reporting electric field measurements is highly desirable. Concern over the difficulty in comparing the results of various measurement programs, prompted the Electric Power Research Institute to develop a draft standard reporting format for EPRI sponsored electrostatic field measurements. The reporting format was developed in an EPRI sponsored workshop, which resulted in the outline of the principal items which were considered to be essential in reporting electrostatic field measurements. Although EPRI does not consider the resultant reporting format as a "standard" in that sense of the word, the resulting format does provide for the documentation of the essential elements associated with electric field measurements. Table 2.3 presents the format developed by EPRI. The use of this or related formats for reporting electric field measurements, made either beneath transmission lines, or as a part of laboratory experiments investigating the biological effects of electric fields, is of significant importance.

Commercially available electric field meters appear to be sufficiently accurate and quite suitable for use in measuring the fields beneath power transmission lines. However, these same meters may not be equally as applicable for measuring the fields in laboratory chambers that are used to simulate electric fields for biological experiments. Commercially available electric field meters are often not small relative to the dimensions of laboratory exposure chambers; thus, the fields indicated by these devices are not a true measure of the fields within the chambers.

IIT Research Institute has developed an electric field probe that has been used to characterize the fields within laboratory field simulators used in Navy sponsored biological test programs (Formanek, 1974). Figure 2.9 shows a photograph of this probe in its voltage reference calibrator. Since this

Table 2.3

STANDARD EPRI REPORTING FORMAT FOR ELECTROSTATIC FIELD MEASUREMENTS

This reporting format outlines the data which must accompany Electrostatic Field Strength Measurements in EPRI Project Reports. The measurements of field strength shall be presented in the format __kV/m ± __.

1. Definitions and Assumptions

1.1 Electrostatic field assumptions

1.1.1 Boundary Assumptions (uniform or nonuniform field)
1.1.2 Vector component treatment (vertical component only or other)
1.1.3 Corona conditions of time of measurements
1.1.4 Field assumed to be disturbed or undisturbed
1.1.5 Field source (single-phase, three-phase, or dc)
1.1.6 Field source frequency and harmonic content

1.2 Magnetic field conditions

1.2.1 Magnetic field conditions assumed to exist and their effect on the electrostatic field measurements, if any.

2. Electrostatic Field Measuring Equipment Data

2.1 Basic Data

	Probe	Detector
2.1.1	Equivalent circuit and reference (grounding method)	Equivalent circuit (input impedance, etc.)
2.1.2	Frequency response	Frequency response
2.1.3		Reading characteristic (rms or other)

2.2 Description

2.2.1	type, model, description	type, model description
2.2.2	physical size	rated accuracy
2.2.3	immunity to electromagnetic interference	immunity to electromagnetic and electrostatic interference
2.2.4	temperature or humidity effects	temperature or humidity effects
2.2.5	length and characteristics of holding device or handle	correction factor if used (for meter orientation or other)
2.2.6	Connecting cable (type and description)	

2.3 Calibration

2.3.1	Method, procedure and description	Method, procedure and description (if different than probe calibration)
2.3.2	Level of corona onset (undisturbed field)	

3. Measuring Techniques

   3.1 Distance from the ground (assumed, vertical, other)

   3.2 Orientation of the probe (horizontal, vertical, other)

   3.3 Proximity and geometry of intruding objects

   3.4 Grounding technique and description

4. Field or Experimental Condition

   4.1 Ambient/Natural Condition

      4.1.1 Indoor or outdoor
      4.1.2 Weather or room conditions (temperature, humidity, wind, precipitation, etc.)
      4.1.3 Characteristics of test area (soil type, ground cover, pavement, etc.)

   4.2 Physical Conditions

   The required data in this category is different for transmission lines, substations, or laboratory measurements.

      4.2.1 Transmission Lines

         4.2.1.1 Span and sag
         4.2.1.2 Conductor type and configuration
         4.2.1.3 Line-to-line and line-to-ground voltage
         4.2.1.4 Metallic ground system and/or shield wire description
         4.2.1.5 Tower type
         4.2.1.6 Measurement locations (relation to towers and lines)
         4.2.1.7 Other electrostatic field sources or physical objects in the area

      4.2.2 Substations

         4.2.2.1 Line-to-line and line-to-ground voltage
         4.2.2.2 Plan and elevation drawings (including buildings, fences, transformer, temporary structures, etc.)
         4.2.2.3 Grounding conditions (stone cover depth, ground mat depth, etc.)
         4.2.2.4 Bus and/or line configuration and description
         4.2.2.5 Phasing and harmonic content of sources in the area of the test
         4.2.2.6 Energization condition and phasing of adjacent bays

      4.2.3 Laboratory

         4.3.2.1 Test setup description and drawing
         4.3.2.2 Description of any conducting and/or nonconducting intrusions which might be present
         4.3.2.3 Grounding and shielding techniques used
         4.3.2.4 Power supply description (voltage, frequency, phasing, harmonic distortion)

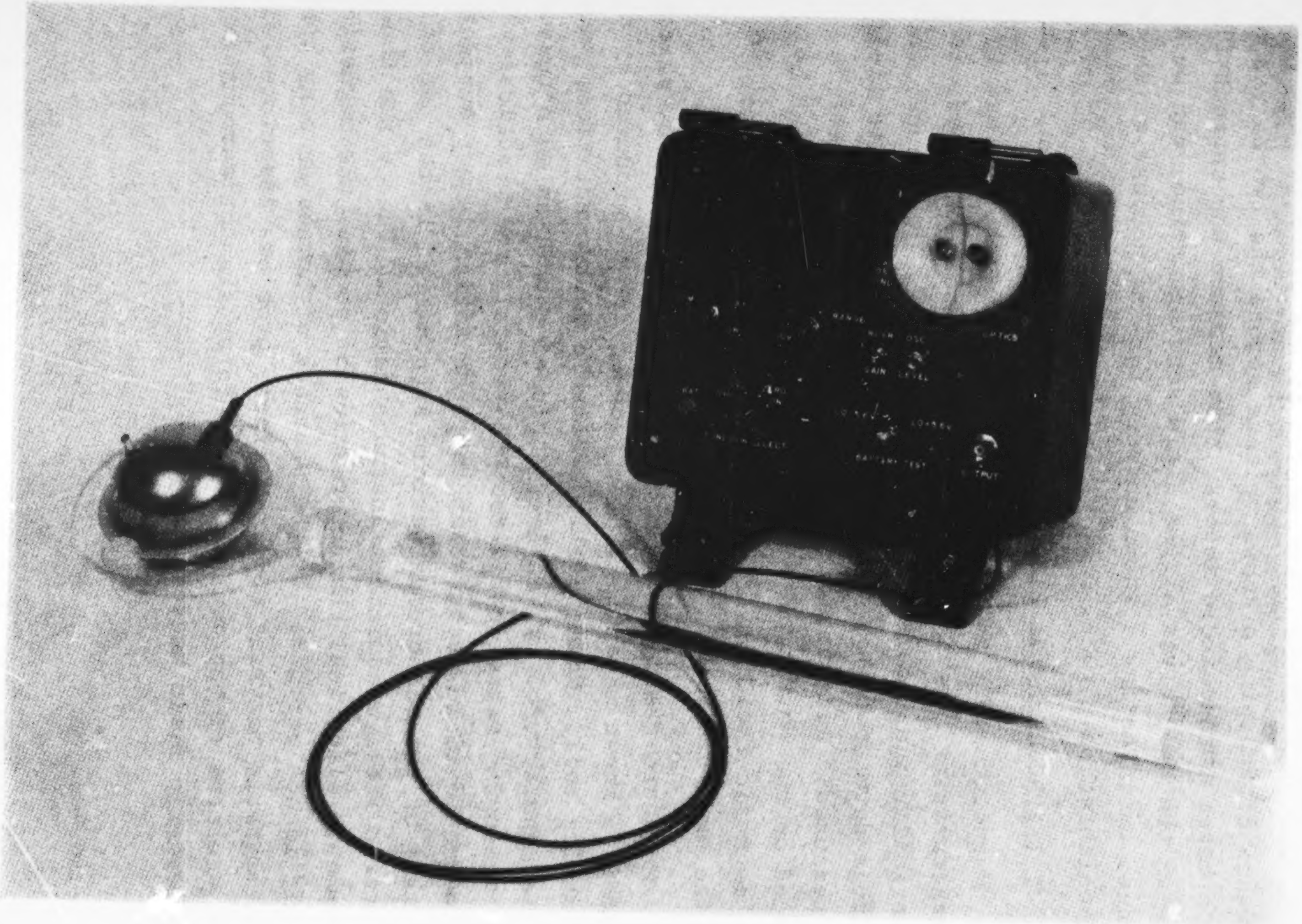

Fig. 2.9 IITRI ELECTRIC FIELD PROBE AND RECEIVER/CALIBRATOR

probe measures the voltage developed by the field across the two halves of a sphere, referencing of the probe is accomplished by means of applying a known voltage across the two halves of the sphere. Other field meters, that measure the current flow between the two halves of the field sensing device, can be referenced by injecting a known current for the purpose of checking the calibration.

2.1.3.3 Magnetic Field Instrumentation

Magnetic field measurement instrumentation, for use in characterizing the fields from 60 Hz transmission lines, is practically and theoretically quite simple. In essence, the voltage developed in a multi-turn loop by the magnetic field is measured. Alternately, if a current sensing element is placed on the output of a loop, the current flow caused by the magnetic field can be linearly related to the magnitude of the magnetic field.

Magnetic field probes are generally calibrated by placing them in a known magnetic field, such as can be produced by a Helmholtz coil. Commercially-available instrumentation, such as is manufactured by Polytek, includes a coil as an accessory for measuring magnetic fields. In general, the practical use of magnetic field measurement instrumentation is not subject to many of the measurement errors encountered in the use of electric field measurement instrumentation. Due to the non-permeable electrical characteristics of people, the magnetic field is not perturbed by the presence of humans or many other non-magnetic material objects. Thus, problems associated with the nearness of the measurement operator are not encountered in magnetic field measurements.

2.2 Quantitative Description of Voltages and Currents Induced in Objects by the Fields

The electric and magnetic fields produced by transmission lines can transfer energy or power from an energized transmission line to other conducting objects. The object to which these fields couple can be animate, such as a person, animal or plant, or inanimate such as vehicles, fences, metallic portions of buildings, etc. The principal effect of the electric and magnetic fields is to cause voltages and/or currents to be induced on the objects in the field. The voltages and currents induced directly onto animate objects are of concern if they are high enough to cause direct biological, physiological or psychological effect. Voltages and currents induced in inanimate objects are also of concern, due to the secondary effect which may occur when an animate object comes into contact with the electrified inanimate object. The voltages and currents induced in inanimate objects are also of concern if they are high enough to cause modifications to the normal function or performance of the object. Examples of this latter case include the possibility of explosions in areas of concentrated fuel vapors, enhanced corrosion of pipelines, or performance degradation of telephone circuits.

In order to quantitatively assess the effects of induced currents and voltages on either animate or inanimate objects in the field of transmission lines, it is necessary to be able to relate these currents and voltages to the field which produces them. Analytical techniques have been developed for the purpose of predicting the currents and voltages which will be developed on objects by the fields of transmission lines. Measurement procedures have also been developed, and the results of these measurements compare quite well with the values predicted on an analytical basis. This section will discuss the analytical procedures and measurements, as they relate to the various types of coupling and objects. The following two sections discuss the effects of these fields, currents, or voltages on people, plants and animals.

The induction of voltages and currents into objects by transmission lines can be divided for discussion into the effects due to the electric fields and the effects due to magnetic fields. By and large, the effects due to the electric fields, termed electrostatic induction, are those effects most likely to be encountered by the public. Magnetic field induction effects, termed electromagnetic induction,* are most prevalent in connection with very long objects that parallel the transmission line, such as telephone circuits, pipelines, rail facilities, and unenergized transmission lines being erected in the near vicinity of an already energized line. Thus, it is seen that most of the magnetic field induction effects are not of direct concern to the public; however, these effects must be taken into account to insure the harmonious operation of other utilities. Magnetic fields can, however, cause circulating currents in persons or other large animate objects; thus the magnetic fields are important to the general population from this aspect.

The quantitative description of the voltages and currents induced in objects by transmission lines, requires different analytical procedures, depending on whether the induction is electrostatic or electromagnetic. Therefore, the discussion of the induced voltages and currents will be separated into electrostatic induction and electromagnetic induction.

2.2.1 Electrostatic Induction

2.2.1.1 Induced Current and Voltage

The procedures to assess voltages and currents caused by the electric field are independent of whether the object is a person or an inanimate object. The time varying electric field

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*The use of the terms electrostatic and electromagnetic as identified here is a convention widely employed in the power industry. More generally, however, (outside the power industry) the term "electromagnetic" encompasses all electric and magnetic field phenomena. An attempt has been made in this document to employ the terminology consistent with the power industry usage.

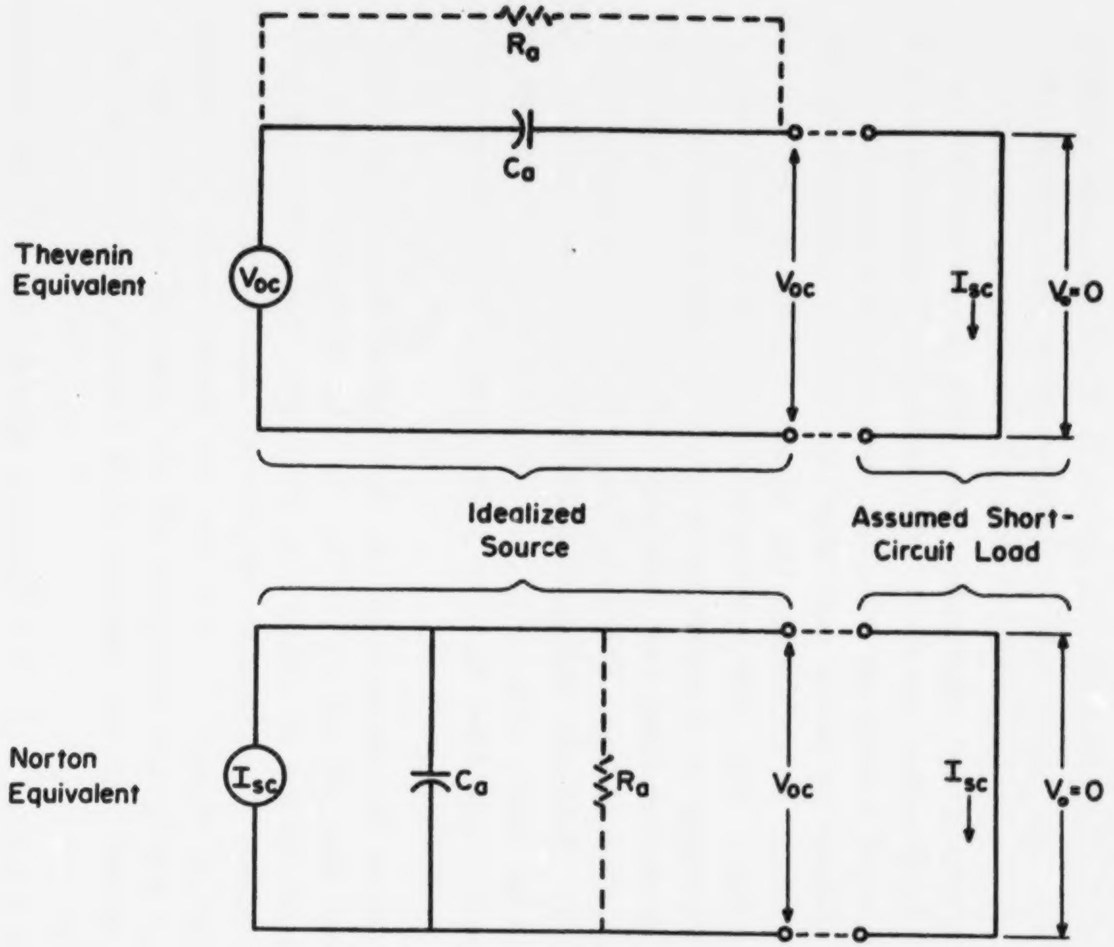
R_a
C_a
Thevenin Equivalent
V_{oc}
V_{oc}
I_{sc}
$V_o = 0$
Idealized Source
Assumed Short-Circuit Load
Norton Equivalent
I_{sc}
C_a
R_a
V_{oc}
I_{sc}
$V_o = 0$

Fig. 2.10 IDEALIZED NON-REALISTIC THEVENIN OR NORTON EQUIVALENT CIRCUITS FOR ELECTRICALLY SMALL METALLIC COLLECTOR NEAR GROUND

that is produced by the transmission line causes a time varying charge, or current flow to be induced on a nearby conducting object.

The calculation of voltages and currents induced on representative objects by the electric field has been studied extensively, and analytical procedures have been widely reported. The basic phenomenon is well understood; however, different analytical approaches have been developed for obtaining quantitative results. For example, Tranen and Wilson, 1971, describe a computer program that utilizes matrix procedures similar to those described for use in determining the electric field, to calculate the charge induced on the surface of the object. The IEEE Working Group on E/S in Part 2 of their 1971 paper on Electrostatic Effects, describe the procedure for determining the coupling to an object in terms of the admittance between the object and the transmission line conductors. Probably the most widely used procedures are those presented by Deno, 1974, 1975, who develops the concept of the object equivalent area and its collection of displacement current.

Although the details of the analytical procedures vary, in general the problem is reduced to the development of a Thevenin or Norton equivalent circuit for the object. Figure 2.10 shows the Thevenin and Norton equivalent circuits for a typical object located near the ground. In this figure, V_{oc}, I_{sc}, and C_a are functions of the geometry of the conducting object and its location with respect to the transmission line.

The value of V_{oc}, the Thevenin equivalent voltage developed on the object, is roughly proportional to the average height of the object for objects that are small compared to the height of the transmission line and located near the ground, and is directly proportional to the electric field at the object location. A relationship that is widely used in antenna theory, as well as for object electrification beneath transmission lines, is that the open circuit voltage is related to the electric field by a factor that is denoted the "effective height," that is, $V_{oc} = E_v \times h_e$, where h_e is the effective height of the object, and E_v is the vertical electric field intensity. For example, for vertical cylinders near the ground, that are electrically short compared to a wavelength, $h_e = h/2$ where h is the physical height of the cylinder.

The Norton equivalent short circuit current, I_{sc}, is most readily visualized and analytically assessed in terms of the displacement current that is collected by the object. Displacement current is the current which flows through a non-conducting medium (such as air) when an electric field exists in the medium. For example, the current that flows through a capacitor, due to time varying voltage across the capacitor, is displacement current, as opposed to conduction current which flows through a conductive medium.

The collection of displacement current can be visualized by considering the object as a current collecting area. Consider an area in space that is planar and normal to the vertical electric field vector. By virtue of the electric field, displacement currents in air will flow through this area. The amount of displacement current which flows through this area is proportional to the size of the area, the time derivative of the electric field intensity, and the permittivity of the air medium. Thus, given the size of the area and the electric field, one can determine the total displacement current which will flow through that area. The total displacement current flowing into this area is equal to the total current flow to ground, if the area is an adequate representation of the physical object of concern.

Deno, 1974, 1975, and in the Transmission Line Reference Book, 345 kV and Above, develops the procedures for relating the dimensions of a physical object to an equivalent area that will collect the same displacement current, as the physical object. Thus, the use of these procedures enables the determination of I_{sc} for practical objects. For simple objects, such as rectangularly shaped objects or flat plates, Deno presents normalized curves or charts for determining the short circuit current to ground in terms of the unperturbed electric field at ground level.

The impedance elements shown in Figure 2.10, that is, C_a and R_a, are a complex function of the object geometry. In the cases of interest, R_a arises from the finite air conductivity but is so large that it can be neglected. The object capacity, C_a, can be calculated for simple objects such as cylinders or spheres.

A more realistic circuit, for practical objects very close to the ground, such as a vehicle, is shown in Figure 2.11. This figure includes impedance elements not included in the previous figure, such as a capacitance and a resistance to ground, which for a vehicle are largely determined by the tires. The capacitance to ground, here designated as C_{ins}, is analogous to the stray base capacity considered in antenna work due to the close coupling of portions of the object to ground. The resistive term, R_{ins}, is a leakage resistance term, and for vehicles is contributed by the tire leakage.

Many comparisons between calculated and measured values for object short circuit current have shown that very good agreement exists between the calculated and measured values. However, in the case of the object open circuit voltage, V_{oc}, the calculated and measured values often differ significantly, with the measured value being less than that calculated. This can be explained by the fact that when measurements are made, the open circuit voltage is measured at the point indicated by V_L in Figure 2.11, while, in general, the voltage calculated is the true open circuit voltage, V_{oc}, of that same

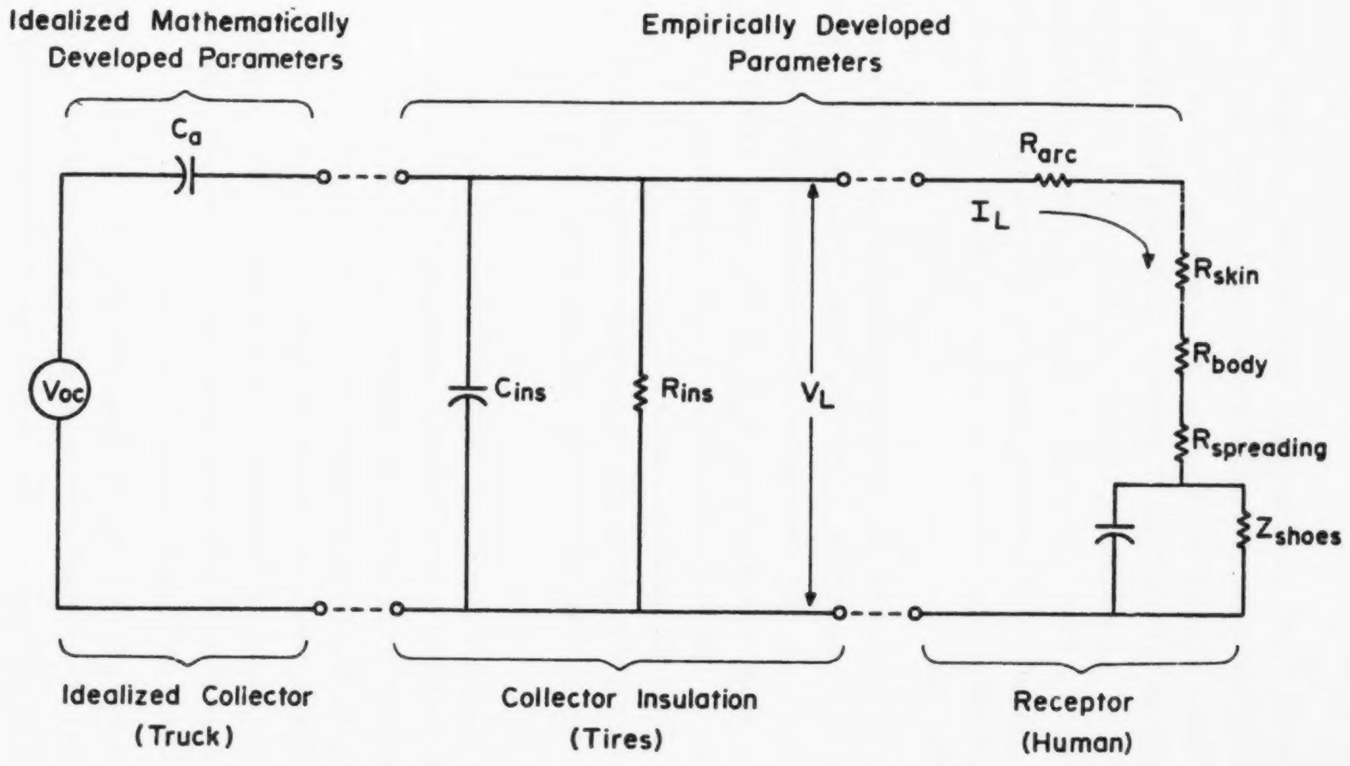
Idealized Mathematically Developed Parameters
Empirically Developed Parameters
C_a
R_{arc}
I_L
R_{skin}
R_{body}
$R_{spreading}$
Z_{shoes}
V_{oc}
C_{ins}
R_{ins}
V_L
Idealized Collector (Truck)
Collector Insulation (Tires)
Receptor (Human)

Fig.2.11 REALISTIC THEVENIN EQUIVALENT CIRCUIT

diagram. The difficulty in adequately establishing a value for C_{ins} and R_{ins} analytically, gives rise to the noted discrepancies.

From the practical standpoint, the values of open circuit voltage and short circuit current that are induced on the object by the electrostatic field are of concern. However, the current actually delivered to a person touching the object is of more importance in determining the effect of such charged objects on humans. Thus, in Figure 2.11, a reasonable equivalent circuit, which takes into account the human, is also included. The human equivalent circuit is shown on the right of the noted diagram.

It is seen that several impedance elements contribute to the overall equivalent circuit of the human receptor. Included are the resistance of the arc which may be established on contact, R_{arc}; the skin resistance, R_{skin}; the body resistance, R_{body}; a spreading resistance, which is an increase in resistance due to a limited contact area, $R_{spreading}$; and the impedance of the individual to ground, here represented by a resistive and capacitive component of the shoe impedance to ground.

Most of the equivalent circuit components in the representation of the human are strongly influenced by a wide variety of factors that are difficult to control or to analyze. Factors which influence those components of the human equivalent circuit include the weather (such as precipitation and humidity), soil conditions (such as dampness, sponginess, and conductivity), and the details of the footwear worn (such as the thickness of the soles, and their conductivity).

Although many of the above factors are difficult to include on an analytical basis, they can be determined by measurement. In the process of determining, on a realistic basis, the effect of such electrified objects on humans, a statistically significant assessment of these parameters should be included. However, to date a comprehensive evaluation of these parameters as a function of terrain, weather, clothing, and vehicular parameters, has not been made. Thus, in general, the power companies have assessed the current flow to humans on either the basis of the short circuit current, or the current as measured through a low value of resistance, typically 1500 ohms, to ground. This procedure results in a worst case assessment of the current which will be delivered to a human when contacting such an electrified object.

2.2.1.2 Measurements

The power companies have been active in the determination of the electrostatic induction to a large variety of practical objects by measurement programs; see for example Zalewski, 1976; Perkins and Nowak, 1977. In addition, Bracken, 1975, reports the results of an electrostatic measurements program held in conjunction with the IEEE Working Group on E/S and E/M effects of transmission lines. The results presented by Bracken compared both measured and calculated results for a variety of vehicles and other objects such as metallic roofing, gutters, and irrigation pipe. In addition, measurements were also made on the electrostatically induced voltages and currents on a reasonable sampling of people. Several important factors concerning the electrostatic induction to vehicles were identified by Bracken, namely:

1. Short circuit current is an easily measured and adequately predictable quantity for vehicles under transmission lines.
2. Open circuit voltage is very dependent on surface and weather conditions. Maximum open circuit voltage can be realized only with dry insulation and with a smooth surface to provide a low virtual ground.
3. The variation in electrical phase angle over the extent of the vehicles used in this case is not significant. Induced currents were almost equal for vehicles parked parallel and perpendicular to the line.

4. The simple parallel RC circuit is a useful model for the linearized vehicle impedance to ground. The capacitance of a vehicle to ground is very dependent on the surface conditions and insulation.

The theory of electrostatic induction predicts that both V_{oc}/E, and I_{sc}/E are constants. That is, once the characteristics of a particular kind of vehicle are determined, either analytically or by measurement, the current or voltage should be predictable by this characteristic and the electric field for any other condition of electric field. The comparison between measured and calculated values as provided in Bracken show that a good comparison between measured and calculated values for I_{sc}/E exists. This can be seen by the data shown in Table 2.4, which is reproduced from Bracken, 1975. This table is informative, because it shows the good correlation between calculated and measured values for short circuit current. It also shows the significant differences that can be obtained between different methods of calculating the open circuit voltage, and the differences between these calculated values and measured values. For the above data, electrical isolation of the vehicles was provided by a 0.63 cm thick rubber "hot line" blanket under each tire.

Zalewski, 1976, illustrates the care that must be exercised in measuring or predicting the open circuit voltage of a vehicle. He shows that for an insulated vehicle, the capacitance from the tires to ground can be greater than the capacitance from the chassis to ground, thus significantly influencing the value of open circuit voltage measured. He also shows that if insulated measurements are to be made, significant care in the choice of the insulator is necessary. Using such materials as plywood results in a leakage path to ground which will further reduce the open circuit voltage values.

Table 2.4

INDUCED CURRENTS AND VOLTAGES FOR VEHICLES
(from Bracken, 1975)

Location Orientation		Road (Span 2) Parallel	Road (Span 2) Perpendicular	Field (Span 3) Parallel	Field (Span 3) Perpendicular
a. Travelall					
I_{sc}:	measured[+]	.33,.64,.43	.33,.64,.48	,1.18,	.64,1.2,.50
I_{sc}/E:	measured (mean)	.13	.13	.11	.12
	calculated[†]	.15,.14,.12			
V_{oc}:	measured[+]	.55,1.01,.65	.54,1.12,.78	,1.70,	.70,1.4,.70
V_{oc}/E:	measured maximum	.22	.23	.16	.17
	calculated maximum[†]	.33,.37,1.16			
b. Sedan					
I_{sc}:	measured	.28,.55,.38	.32,.47,.35	,.90,	.48,.9,.4
I_{sc}/E:	measured (mean)	.11	.11	.085	.088
	calculated	.11,.11,.10			
V_{oc}:	measured	.52,1.05,.72	.46,.80,.43	,1.2,	.23,.50,.50
V_{oc}/E:	measured maximum	.21	.18	.11	.12
	calculated maximum	.29,.29,.87			
c. Camper					
I_{sc}:	measured	.77,1.42,1.01	.82,1.36,.95	,2.85,	1.4,2.6,1.2
I_{sc}/E:	measured (mean)	.28	.29	.27	.26
	calculated	.25,.26,.25			
V_{oc}:	measured	.87,1.46,1.18	.73,.92,.70	,2.8,	1.0,1.7,.95
V_{oc}/E:	measured maximum	.35	.29	.27	.23
	calculated maximum	.44,.59,1.79			

* Units: I_{sc},mA; I_{sc}/E,mA/(kV/m); V_{oc},kV; V_{oc}/E,kV/(kV/m).

[+] Values represent measurements at 0, 10, and 20 m from centerline respectively.

[†] Calculated values represent values predicted independently by three groups.

The measurements presented by Perkins and Nowak, 1977, are highly significant, in that they not only present short circuit current measurements for a large variety of vehicles, but they also address the more practical problem of the current flow to an individual touching the vehicle. The data of Perkins and Nowak show, as have others, that the vehicle short circuit current to ground, is virtually independent of whether or not the vehicle is insulated from ground. However, more importantly, they show that there is a significant difference in the current flow through a person touching the vehicle, depending on whether or not the vehicle is insulated from ground.

They show that a person, who touches a vehicle which is in normal ground contact, will receive a very small percentage of the vehicle's short circuit current. This is because the majority of the current will flow through the tires of the vehicle rather than through the higher resistance path of a human, the human impedance being typically comprised of elements such as were shown in Figure 2.11. Their tests show that for large objects, whose short circuit currents are above perception levels, a man will generally receive less than 5% of the uninsulated object's current. In contrast, a well grounded person was found to receive up to 93% of the short circuit current from a well insulated object.

The results of these tests are significant in the consideration of the potential hazards associated with electrified objects beneath transmission lines. It appears from these measurements that: 1) the use of open circuit voltage data or calculations based on insulated vehicles, and 2) the use of short circuit current data for vehicles, are both very worst-case considerations. Additional data collection, which takes into account all elements of the equivalent circuit shown in Figure 2.11, by carefully controlled measurements under a large variety of realistic conditions, is warranted if the true influence of such charged objects on humans is to be assessed.

The electrostatic field not only couples to metallic objects such as vehicles, fences, gutters, etc., but also couples directly to humans in the field, and causes current to flow through the human. The current that flows through the human due to the electric field is a highly important aspect with regard to potential biological interactions. If there are biological effects that are caused by the electric fields of power lines, it is likely due to the current induced in the body by these fields. Therefore, a close examination of these currents is important for the purpose of relating a wide variety of biological experiments.

The measurements reported by Bracken, 1975, included measurements made on men, women, and children, to determine the relationship between the short circuit current to ground from the individual, as it relates to the electric field and the height of the individual. The analysis of the test data shows that the data can be approximated by the equation

$$I_{sc} = 5.4\ h^2 \times E$$

where

I_{sc} is in microamperes

E is the field in kV/m, and

h is the height of the individual in meters.

These results are in good agreement with other investigators such as Schneider, et al., 1974. In addition, an extensive series of measurements has been made by Deno, 1977, utilizing a metallized mannikin. His results substantiate those reported in Bracken and provide considerable additional data, such as the current distribution along the height of the individual standing in the field.

Using the above expression, the current induced in a person due to a 10 kV/m electric field, is found to be 175 μA when the person is 1.8 meters tall. This level of body current may be placed in perspective with the current which can arise from more familiar items such as household appliances. The American National Standards Institute (ANSI) has developed standards for the allowable values of leakage current (to humans) from appliances. In essence, the standards limit the leakage from cord-connected portable appliances to 500 μA, and the leakage from cord-connected stationary appliances to 750 μA. For an appliance to pass Underwriter tests, it must have less leakage current than the above limits. Thus, it is possible for a person to be exposed to more body current, from contact with normal household appliances, than when standing erect directly below a 765 kV transmission line.

The current flow paths through the body, however, are not likely to be the same for these two cases. The work by Deno, 1977, shows that, for example, the current flow through the neck region of a person standing in an electric field will be approximately 1/5 of the current flow to ground. For the above example, this represents a 35 μA current through the neck, which would not normally flow due to appliance contact. The Deno work, as well as that of Bridges and Frazier, 1976, shows that if the person under the line is not grounded, the current flow in the mid portions of the body will be approximately 1/2 of that which flows under well-grounded conditions. As Deno points out, the actual current flow under ungrounded conditions is highly dependent on the conductivity of the shoes and other factors. It is thus difficult to estimate this current for the typical case; however, the grounded case is an upper limit.

The Deno work also considers the case where a person is elevated above the ground, for example, standing on a conducting object. He shows that the current flow as a function of position in the body will be modified by a factor of

$$\left[1 + \frac{\text{clearance}}{h/2}\right] \left[1 - 0.1\,\frac{\text{clearance}}{h/2}\right]$$

where

h is the height of the man, and

(clearance) is the distance between the bottom of his feet and ground.

Thus, for a man standing on, and grounded to, a conducting object that is equal to his height, the current flowing in him will be

$$\left[1 + \frac{h}{h/2}\right] \left[1 - 0.1\,\frac{h}{h/2}\right] = 2.4 \text{ times}$$

that which flows when he is on the ground.

2.2.1.3 Field Enhancement

When an object is introduced into a uniform electric field, that field is distorted. For most three-dimensional objects of concern, the introduction of such an object into a uniform field causes the field to be enhanced, or made larger than the original field, near surfaces which are normal to the original direction of the electric field. Near surfaces that are parallel to the original field direction, the field is generally decreased. The field enhancement which occurs near the upper surfaces of objects is a function of the height of the object and other geometrical characteristics of the object. For tall, thin objects in the field, the field enhancement at the top of the object is related to the length to diameter ratio of the equivalent object. Greater field enhancements at the upper surface of the objects occurs for larger length to diameter ratios. Enhanced electric fields may give rise to an awareness of the field due to stimulation of hair follicles. In addition, for very long, thin objects such as leaves or blades of plants, the field enhancement at points may be sufficient to cause corona to occur at these points, if the unperturbed field is sufficiently high.

Schneider, et al., 1974, shows the results of calculation of the field enhancement at the top of the head of a person, modeled as a cylinder with a half-sphere top. In their calculations, the overall cylinder height was 175 cm, the cylinder diameter was 25 cm, and the cylinder was grounded to the earth plane. They found that the field at the top, of the half-sphere capped cylinder, was a factor of 15 greater than the original uniform electric field.

Barnes, et al., 1967, provides an analysis of a prolate spheroid model of man in an electric field. When the original electric field is parallel to the major axis of the prolate spheroid model, the electric field enhancement is found to be a function of the ratio of the major semi-axis to the minor semi-axis, increasing with larger ratios. An example given, chooses to represent the major semi-axis dimension A = 36 in, and the ratio A/B = 4.5, where B is the minor semi-axis. For this geometry, the ratio of the electric field at the top of the prolate spheroid to the original electric is found to be a factor of 15.5, which agrees quite well with the enhancement factor cited by Schneider, et al., for their model of man.

Barnes, et al., 1967, in their analysis of the prolate spheroid also developed another interesting observation concerning the current density within the material of the prolate spheroid. If the interior of the prolate spheroid is considered to be a uniform resistive material, it is found that the interior current density is uniform, and its vector is parallel to the original, or unperturbed electric field. Barnes presents tabulated results which enables the determination of the current density and total current to the prolate spheroid as a function of the ratio A/B and the unperturbed electric field. Using their tabulated data and the model dimensions given above, it is found that for an incident unperturbed electric field of 10 kV/m, the current density within the spheroid is $J = 0.33 \times 10^{-6}$ A/inch^2 = 5×10^{-4} A/m^2.

2.2.1.4 Secondary Effects

A non-biologically related effect of the electrostatic induction from EHV transmission lines which has been studied in a preliminary manner by several investigators, is the possibility of the undesired ignition of fuel vapor by arcs. It has been postulated that when a truck is refueled beneath a power line, an arc can be developed between the gasoline can spout and the filler pipe on the vehicle. This arc could conceivably supply sufficient energy to ignite fuel vapors which could lead to an explosion. Similar situations can be conjectured for other flammable mixtures or for explosives, and a variety of different conducting object configurations.

Some of the uncertainties previously discussed in conjunction with Figure 2.11 are very important in determining the likelihood of such an event for practical situations. When considering a vehicle as the charged object, the leakage resistance of the tires and/or the tire capacitance to ground will play an important role in establishing the open circuit voltage of the vehicle. Both the open circuit voltage and the capacitance of the object play an important role in determining whether or not a problem can exist with explosive fuel vapors.

The majority of investigations, which have been reported for determining the parameters associated with the ignition of fuel air vapors, have been conducted on a very idealistic basis. These investigations have been conducted under laboratory conditions, or with well-insulated charge collecting objects. These investigations have been conducted for the purpose of establishing the energy necessary for causing fuel air vapor ignition.

For practical situations, the possibility of ignition also depends on a variety of meteorological conditions. The geometry of the electrode which causes the arc is also a factor. The larger the electrodes the more easily they can dissipate the heat of the arc; thus, more energy will be required to ignite the mixture. As a basis for considering the likelihood of a charged vehicle igniting fuel air vapor mixtures, most investigators cite the works of McKinney, 1962; Eichel, 1967; or Lewis and von Elbe, 1951. The ignition threshold estimates range from 0.25 mJ to 0.5 mJ.

Reiner, 1971, has conducted tests using a well-insulated car near a 500 kV transmission line and has determined the stored electrostatic energy as a function of distance from the line. His results show that a stored energy of 0.5 mJ is exceeded if the vehicle is closer than 45 ft from the outer conductor of the transmission line.

Shankel, 1965, reports a qualitative test to determine the possibility of gasoline ignition. In this experiment, a rough container was formed of aluminum foil and mounted on a 100 ft length of well-insulated fence wires. In each ignition test the insulated fence was allowed to charge and then discharge to a ground probe thrust into the aluminum foil cup. The cup contained approximately 2 tablespoonsful of gasoline. The energy of the charged fence was controlled by adjusting the height of the fence above ground. Based on the calculated stored energy of the fence, it was found that ignition of the gasoline was very difficult in the energy range of 0.5 mJ.

Project UHV also conducted tests to determine the ignition of gasoline vapor. The results are reported by Deno and Zaffanella in the Transmission Line Reference Book, 345 kV and Above. In these tests, emphasis was given to a spark discharge, from an electrode that was shaped like a spout, to an open container filled with gasoline which simulated a vehicle tank. It was found that the ignition did not follow a constant energy curve; therefore, it is not possible to refer to the energy as the only parameter characterizing the ignition potential. Based on the data obtained, these investigators present an empirically derived relationship for the minimum ignition voltage. This expression is $V_{oc} = 4.6\ C^{-0.3}$ where V_{oc} is in volts, and C is in farads. They also found that the use of sharp points such as a pin, lowered the minimum ignition voltage to approximately 0.65 times the value obtained when a spout was used.

In order to duplicate the conditions in practice that relate to the conditions used in testing, a vehicle must be well-insulated from ground, such as when it is on dry pavement. Simultaneously, a well-grounded person, such as one standing on moist ground with low insulation resistance shoes, must pour the gasoline and cause a spark to be produced in the region where the fuel vapor and air mixture have an appropriate concentration. The general consensus is that the probability of such occurrences, all happening simultaneously, is quite remote. Lyskov, et al., 1975, concede that the possibility of such ignition in practice is insignificant.

Thus, under contrived conditions, it is possible to demonstrate the ignition of fuels and other flammable mixtures beneath power transmission lines. However, a complete hazard analysis which indicates the probabilities of explosion for different kinds of fuel conditions, meteorological conditions, source voltages and energies and hazard scenarios, under realistic conditions is not available. Additional data obtained under realistic conditions appear to be highly desirable in order to place this potential hazard into perspective, so as to prevent reliance upon data obtained for non-realistic very worst-case conditions.

2.2.1.5 Mitigation Procedures

The objects, which can present potential problems due to the voltage or currents induced on them by electrostatic induction effects of EHV lines, can be segregated for mitigation purposes into two classes--those which are stationary, and those which are movable. In general, these two different types of objects are handled by different procedures.

Stationary objects such as fences, metallic portions of buildings, and other permanent metallic structures are, in general, grounded to earth. An example of procedures used is the Bonneville Power Administration Transmission Line Standard Specification, Part 12, Chapter 1, which was submitted in response to the Federal Register Notice. These specifications provide guidelines for the grounding of fences, both electric and non-electric, the grounding of buildings, and miscellaneous objects, such as gutters and crop supports. These specifications stipulate the manner in which the object is to be grounded and define the objects to be grounded in terms of their size and relationship to the transmission line.

For example, a non-electric fence must be grounded if it is parallel, or nearly parallel to the subject line, and within 125 ft, measured horizontally from the outside conductor, and is at least 500 ft in length. Additional specifications are given for longer lengths of fence that are further from the transmission line. For buildings with metal surfaces or members, the specification states that these will be grounded if they are located within 100 ft of the outside conductor regardless of size. Additional specifications are given for structures located farther from the line than 100 ft. These procedures are a function of the area of the object.

Information supplied by Consumer's Power Company, 1975, in response to the Federal Register Notice, indicates that they ground all stationary objects which have a discharge current greater than 0.5 mA. Also, the Consumer's Power Company has tentatively established that all stationary objects which could develop energy levels greater than 0.1 mJ will be grounded.

Movable objects by their nature cannot be readily grounded, as can fences or buildings. For movable objects, restrictions are generally placed on the size and types of objects which can be used within the transmission line right-of-way. As an example of these restrictions, Commonwealth Edison (see McCluskey, 1974) supplied information, as a part of the Federal Register Response, on the restrictions on land use that are supplied to farmers. It is recommended by Commonwealth Edison that any vehicles operated within the right-of-way be grounded with a grounding strap or chain. In addition, they set forth the following restrictions, which are quoted here.

1. No building or structure should be placed or erected on the right-of-way. (Certain buildings or structures can be erected under lines of 345,000 volts and less, provided our written consent is obtained beforehand.)

2. No irrigation or sprinkling systems should be installed, used or operated on the right-of-way.

3. No tree or crop should be allowed to extend a maximum height of 15 feet above ground under the transmission line.

4. No vehicle or equipment having a height in excess of 15 feet from ground level should be parked, used, driven, transported or stored on the right-of-way. (In addition, no parking of vehicles is permitted under transmission lines in excess of 345,000 volts.)

5. There should be no form of kites or model airplanes on the right-of-way.

6. No ungrounded pipes or other facilities other than non-metallic farm drainage pipes, should be placed on the right-of-way without obtaining prior written consent.

Based on the criteria of a maximum of 5 mA allowable short circuit current for the largest vehicle expected beneath a transmission line, the Consumer's Power Company places the following restrictions on the use of the right-of-way.

> Farm tractors, combines under 12 feet in height, metal farm wagons under 15 feet in height, or any combination of these farm vehicles pulled by a farm tractor not exceeding 50 feet in length (including the tractor) may be used on fee strips and easements with no restrictions. Any other combination of vehicles pulled by any motor vehicle other than a farm tractor must not exceed 30 feet in length when used on a fee strip or easement. Vehicles used on fee strips or easements which exceed these limitations may require that some method of grounding be applied, such as a chain drag. In addition, any vehicle exceeding 20 feet in height will be allowed to operate on fee strips or easements under or near 765 kV lines only with Consumer's Power Company approval. There will be no limitations or special grounding requirements on public roadways for any vehicle.

The Bonneville Power Administration has published a booklet entitled, "Tips on How to Behave Near High Voltage Power Lines." This booklet describes in layman's terms the precautions which should be effected and the practices that are safe near 500 kV transmission lines. It describes the grounding of metal buildings, wire fences, electric fences, and the restrictions on the use of irrigation systems. In addition, it places a restriction of 14 feet in height for vehicles to be used under the line. They request that if the vehicle exceeds this height that the BPA should be contacted prior to moving it under the line. The booklet also suggests that the fueling of vehicles should not be done under the power line or closer than 70 horizontal feet from the outside conductor. The booklet also presents common sense tips and restrictions on kite and model airplane flying, as well as other recreational activities in the vicinity of the lines.

Even though the above restrictions and procedures are promulgated by the power companies, some such as Hackenberry, 1974, believe that the measures are not adequate, and that additional education is required, since the average person does not know the dangerous propensities of the high voltage line. Hackenberry is concerned that while power company employees and other construction workers adequately recognize the safety precautions to be taken in the vicinity of the transmission lines, the public may not recognize the potential for obtaining shocks from handling such common items as long metallic measuring tapes. He is also concerned with the possibility of direct contact with the lines during recreational activities, such as the fisherman casting a wet line and becoming entangled in the transmission line. The potential hazard associated with such events is not unique to EHV lines. The voltage associated with virtually all commercial carrying conductors is sufficient to require extreme care when handling metallic objects or other conductors in their vicinity which may come into contact with the line. Thus, EHV lines do not appear to pose any unique problem in this regard.

2.2.2 Electromagnetic Induction

Electromagnetic induction effects, i.e., magnetic field induction effects, arise due to the current which flows in the phase conductors, overhead ground wires, and the earth itself. Electromagnetic induction effects are, in general, only of concern or significance for very long conducting objects that parallel the transmission line. Electromagnetic induction effects have been principally studied in the context of the multiple use of rights-of-way by power companies and other services. Many of the other services, that may share the right-of-way with the power line, require metallic components that are very long in extent and, in effect, parallel the power line. Examples are communications circuits, pipelines, railroads, and other power lines in the process of being constructed.

Two conditions of the transmission line are of concern in the context of electromagnetic coupling effects. The first is for the line under normal load conditions; the second is when a fault occurs on the line, thus causing abnormally high ground currents to flow.

Electromagnetic inductive coupling to long parallel conductors, in general gives rise to a voltage that is produced on the parallel conductor. This voltage is a function of the length of the parallel conductor. Analytical procedures have been developed to predict the voltages developed on these parallel circuits under two primary conditions. These are: the case when the parallel circuit or conductor is above ground, and the case when the parallel conductor is below ground. Different procedures are required for each case.

In addition to the magnetic field from the transmission line coupling to adjacent long conductors, the magnetic field also causes a current to be induced into persons or animals that are within the field. The level of such currents has been predicted by the use of simple geometrical models.

2.2.2.1 Long Objects Above Ground

Initial concern with regard to electromagnetic induction problems associated with power lines was with respect to the interference between overhead HVAC transmission lines and adjacent above ground communication circuits. Equations presented originally by Westinghouse, 1964, in the Electrical Transmission and Distribution Reference Book, have been used to predict the induced voltage per mile on an above ground conductor due to single phase and 3 phase transmission lines. An equivalent approach, as summarized by the IEEE Working Group on E/M and E/S effects of transmission lines, 1973, uses Carson's series to compute the mutual impedance between the power line conductors and the affected parallel conductor. The International Telegraph and Telephone Consultative Committee (CCITT), 1965, has summarized available prediction and mitigation methods for induced voltages on above ground conductors.

The general procedure used in analyzing the electromagnetic induction effects is to determine the longitudinal voltage per unit length induced into the parallel circuit as a superposition of the voltages induced by each current carrying conductor. That is, if V_x is used to denote the total longitudinal voltage per unit length, it is given by

$$V_x = I_A Z_{AM} + I_B Z_{BM} + I_C Z_{CM} + I_D Z_{DM} + \ldots$$

where I_A, I_B, etc., denote the current flowing in each conductor or ground wire of the transmission line, and Z_{AM}, Z_{BM}, etc., denote the mutual impedance per unit length between the current carrying conductor and the conductor under study. The induced voltage V_x can be determined once the current flowing in each conductor is known, and the mutual impedances are calculated. The IEEE Working Group on E/M and E/S effects of transmission lines, 1973, give the mutual impedance accounting for Carson's correction factors, as

$$Z_M = R_M + j\,X_M \qquad R_M = 10^{-3}\omega\,(0.2528) + \Delta R_M$$

$$X_M = 10^{-3}\omega(0.74113 \log_{10} \frac{1}{s} \sqrt{\frac{\rho}{f}} + 2.4715) + \Delta X_M$$

where

s = spacing between conductors in feet

ρ = earth resistivity in $\Omega \cdot m$

ω = $2\pi f$ with f = frequency in Hz

R_M, ΔR_M, X_M, ΔX_M in Ω/mile

In the above, ΔR_M and ΔX_M are correction factors. The IEEE provides expressions for these correction factors, which will not be repeated here due to their complexity.

For distances less than approximately 300 meters separating the current carrying conductor from the conductor in which the voltage is being induced, the above expressions may be simplified by neglecting the terms ΔR_M and ΔX_M. These expressions are sufficiently complex that digital computers are normally used for their calculation.

Shankel, 1975, has used the Westinghouse equation for mutual impedance to calculate, by use of computer, the voltage induced in a parallel conductor at a height of 20 feet, for various lateral separation distances, for a large variety of transmission line configurations. For the various transmission line configurations, a number of different current conditions are used including balanced currents, single line-to ground-fault, line-to-line fault, and double line-to-ground fault. As an illustration of the voltages induced in an adjacent conductor by a typical transmission line configuration, Shankel's curves for a 500 kV single horizontal transmission tower for the conditions of balanced current, and single line-to-ground fault, are reproduced here as Figures 2.12 and 2.13. In Figure 2.13, two limiting conditions are shown for the fault current. The upper curve shows the condition when the total fault current flows in the ground; the bottom curve shows the limiting condition for all of the fault current flowing in the ground wires, that are located above the transmission line phase conductors.

In using the above type of results to determine precautions which must be applied for personnel safety, the IEEE Working Group on E/S and E/M, 1973, suggest the use of a Thevenin equivalent circuit to determine the current that may flow to a person touching a parallel conductor, such as a fence. Figure 2.14 shows the Thevenin equivalent circuit they suggested. V_{Th} is the longitudinal voltage calculated by the procedures described above for the length of conductor involved; Z_{Th} is the self-impedance of the conductor above ground; R_p is the sum of the contact resistance, body resistance, and ground resistance of the person; and R_g is the

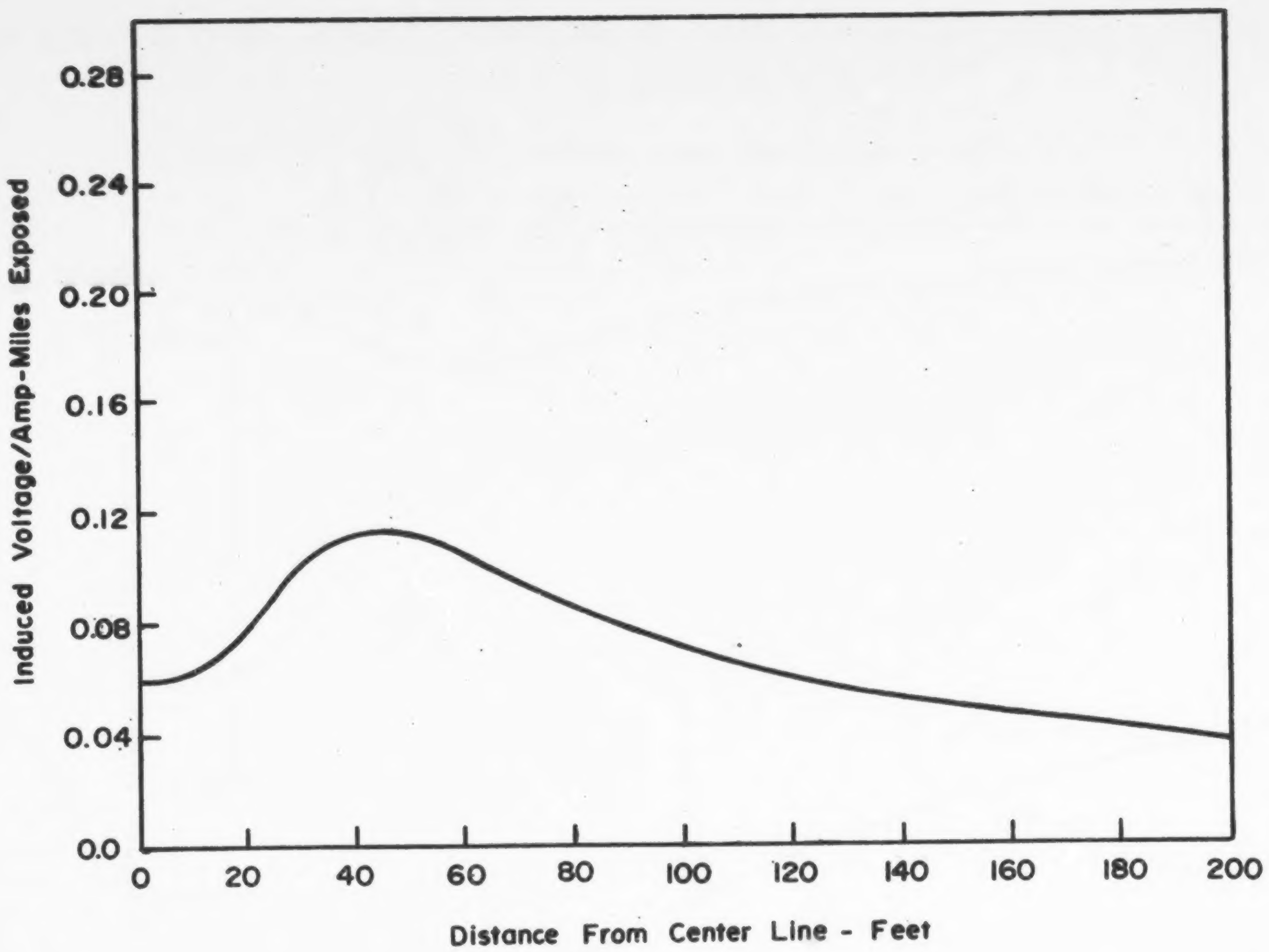

Fig. 2.12 500-kV SINGLE HORIZONTAL TRANSMISSION TOWER, BALANCED CURRENTS (SHANKLE, 1975)

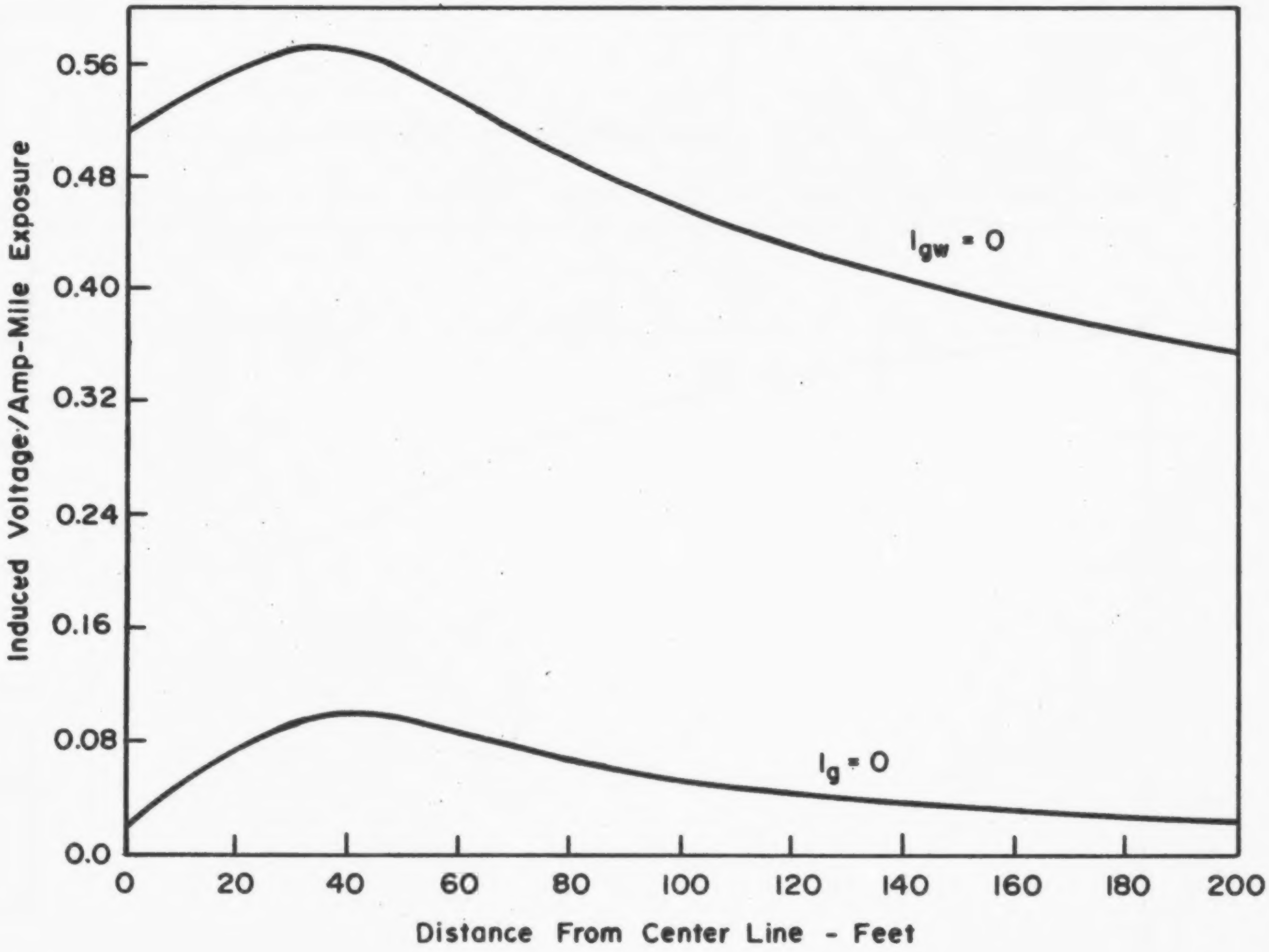

Fig. 2.13 500-kV SINGLE HORIZONTAL TRANSMISSION TOWER, SINGLE-LINE-TO-GROUND FAULT (SHANKLE, 1975)

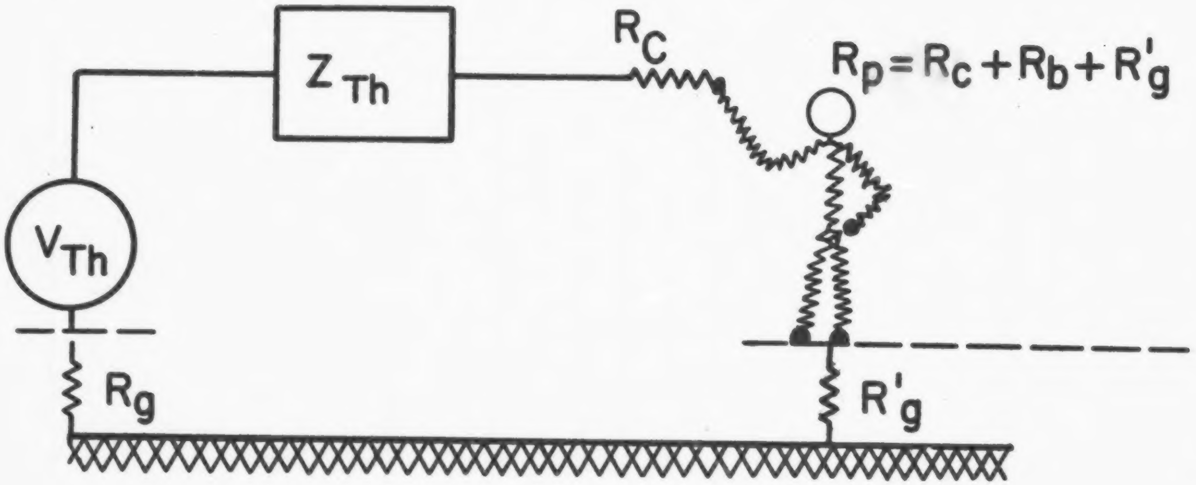
Z_{Th}
R_C
$R_p = R_c + R_b + R'_g$
V_{Th}
R_g
R'_g

Fig. 2.14 EQUIVALENT CIRCUIT FOR ELECTROMAGNETIC INDUCED CURRENT (IEEE, 1973)

resistance at the fence grounding point. Judkins and Nordell in the discussion accompanying the above noted IEEE paper, present expressions for the self-impedance or Thevenin impedance of the conductor of concern, which are based on Carson's original work. Shown in Figure 2.14 are also the resistances associated with a person touching the conductor, and the resistance to ground at the far end of the conductor.

The expression given by the IEEE for determining the current which will flow through the resultant circuit, i.e., through the person, is

$$I = \frac{V_{th}}{(R_g + Z_{Th}) + R_p}$$

As a simplified example of the use of these procedures, the IEEE paper calculates the length of line required to cause a 5 mA current to flow through a person touching the line, when the electromagnetic induced voltage is 0.1 V/mi/A; the total resistance through the person to ground is 1500 ohms; the Thevenin impedance of the line is negligible; and the load current in the parallel circuit is 1000 A. Under these conditions they determine that the length of line to cause this current is 396 feet.

Thus, it can be seen that significant current could flow to a person coming into contact with a very long conductor parallel to an energized transmission line. This is principally a problem for construction crews installing parallel transmission lines or other services on a common right-of-way. The procedure followed by the power companies, on grounding fences or other similar objects, effectively mitigates the problem for the general public. The IEEE publication cited above outlines procedures to be used to protect construction crews from this hazard.

It should be noted, however, that while the construction, operation, maintenance and removal of pipelines in the immediate vicinity of high-voltage power transmission lines have been safely accomplished, it requires strict adherence to safety practices, use of some special equipment, constant monitoring and the cooperation of both energy transportation companies. This past success should not be interpreted to mean that it is desirable to use joint or parallel pipeline-electric power transmission routes but only that joint or parallel routes can be used by these two transportation systems after the application of strict safety and other criteria. The joint use of a pipeline-electric power transmission route must be decided on a case-by-case basis, taking into consideration engineering design, environmental, economic, safety, powerline voltage, joint operating and maintenance concerns and other factors.

2.2.2.2 Long Objects Below the Ground

The previous section has described procedures which are used to determine the voltage induced on long objects above the ground that parallel high voltage transmission lines. The objects of concern there were such things as parallel communications services, rail lines, long fences, and above ground pipelines. When the long parallel conducting object of concern is buried beneath the ground, for example, in the case of a pipeline, it has been found that the analysis procedures described above are inadequate for predicting the voltage that will be induced onto the pipeline. The general form of the equation used to predict the longitudinally induced voltage for above ground objects is $V = f(I,d)L$. Thus, as seen above, the voltage induced is a function of the current flowing in the transmission line circuit, the distance separating the transmission line conductors and the influenced object, and is directly proportional to the length of the influenced object, e.g., the pipe or fence.

A recent report by Dabkowski, 1976, has consolidated known data and made a systematic investigation into the mutual effects of ac electric power transmission lines and natural gas transmission pipelines jointly sharing rights-of-way. Review of the literature on this subject revealed that many investigators had erroneously attempted to apply the above ground results, as exemplified by the above equation, directly to the situation when the pipeline was buried. Uniformly, the values of pipeline voltage calculated using these methods are too high, and several authors estimate that the actual voltage induced was only approximately 10% of that predicted. The above ground methods failed for the buried pipeline case simply because a buried pipeline differs electrically from an aboveground conductor. A buried pipeline, either bare or wrapped in an electrically conductive coating, has a finite resistance to earth, distributed over its entire length; whereas an aboveground line has, at most, point grounds at large intervals. To describe the distributed interaction between a buried pipeline and its surrounding earth, factors such as pipeline diameter, coating conductivity, earth resistivity, depth of burial, and pipe longitudinal resistance and inductance must be taken into account.

Dabkowski, therefore, found it necessary to derive a unified analytical approach to allow the prediction of inductive coupling for both above ground and buried pipeline. The essence of the approach taken is to model the pipeline as a lossy electrical transmission line, assuming a distributed source voltage which is proportional to the parallel electric field existing at the pipeline. The parallel electric field at the pipeline is, in essence, the voltage per unit length obtained by application of the Carson mutual impedance relationships. When the analysis is performed in this manner, it is found that the induced voltage is not proportional to the pipeline length, for long pipelines.

The question of whether ac voltages induced on pipelines by nearby transmission lines cause corrosion, has been a debatable point in the literature. Depending on the investigator, and the conditions of the experiment, various corrosion levels have been reported without apparent correlation. Dabkowski found that the available data sets from many experimenters indicated that at 60 Hz, the corrosion caused in ferrous materials by an ac current is approximately equal to 0.1 percent of an equivalent dc current if no cathodic protection is applied, although some spread in available data exist. He performs an analysis based on consideration of the voltage-current polarization relationships for a corrosion cell. With an induced ac voltage at the corrosion cell, the operating point is shifted sinusoidally with respect to voltage, but due to the nonlinear characteristics of the polarization curve, the resulting anode or corrosion current variation is non-sinusoidal. The assymetrical variation in the anode current results in the generation of a net dc current which appears to induce corrosion equivalent to approximately the 0.1 percent level reported in the literature with no cathodic protection applied.

Dabkowski also suggests techniques for the mitigation of 60 Hz inductive interference to pipeline systems. These mitigation procedures are for the purpose of both reducing the corrosion effects and to reduce the hazards to personnel working with the pipeline, whether it is buried or aboveground. The overall work on this problem is still in progress, and will result in the preparation of a handbook that will detail the state-of-the-art regarding ac effects and corresponding mitigation technologies for use by field personnel.

2.2.2.3 Electromagnetic Induction to Persons

At power line frequencies, the magnetic field completely penetrates the body of a person. That is, the magnetic field is the same inside or outside a person. Due to the sinusoidally varying nature of the magnetic field, eddy currents will be caused to flow inside the body. The electric current which flows within a conducting medium such as a human body circulates in planes that are perpendicular to the direction of the magnetic field. Spiegel, 1975, has analyzed the electric fields developed interior to spherical conducting objects as a result of power line frequency electric and magnetic fields.

Figure 2.15 shows the results of analysis performed by Spiegel for a sphere having the electrical properties of muscle tissue. This figure presents both the induced electric field due to an exterior electric field, and the induced electric field due to an exterior magnetic field, as a function of the exterior field levels. It is seen from this figure that the interior electric field caused by the external electric field, is

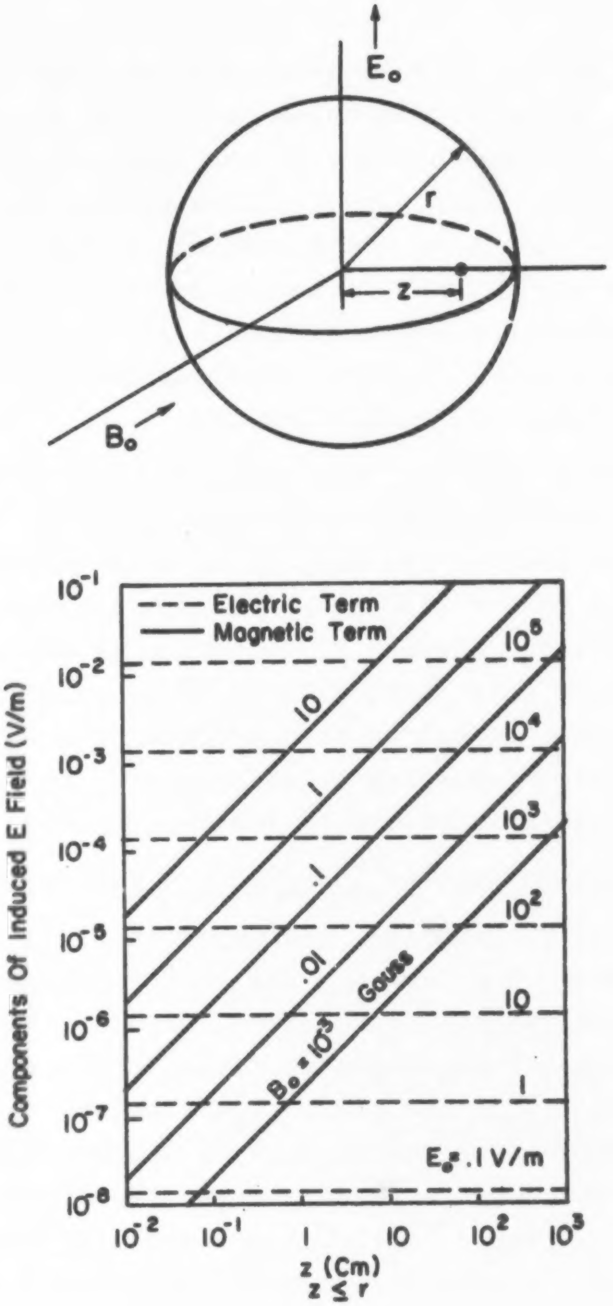

Fig. 2.15 COMPARISON OF THE ELECTRIC AND MAGNETIC TERMS OF THE INDUCED 60 Hz ELECTRIC FIELD AT POSITIONS ALONG THE Z AXIS OF A SPHERE (FROM SPIEGEL, 1975)

independent of the size of the sphere, or the position within the sphere; while the contribution due to the magnetic field is a function of the position within the sphere. Thus, the component of interior electric field due to the magnetic field is maximum at the periphery of the spherical object. In relating this geometry to man, Spiegel suggests the use of a 26 cm radius sphere, as a representation of a 70 kg man. By use of this figure, it is seen that for the geometry and electrical properties assumed by Spiegel, that an exterior electric field of 10 kV/m, and a magnetic field of approximately 0.2 G, will each produce the same level of internal electric field near the surface of the spherical object. The spherical object geometry used in this analysis is probably not as well suited for determining internal electric fields or current density due to electric field excitation as is the use of a prolate spheroidal model, or measurements made of current flow on mannequins, such as has been done by Deno.

A simple expression for determining the electric field interior to a conducting spherical object as a result of the magnetic field is given by the National Academy of Sciences, 1977, as

$E_I = frB\pi$ where

where

E_I is the interior field in volts/meter

r is the distance from the center of the sphere in meters

f is the frequency in Hertz, and

B is the magnetic flux density in Wb/m^2.

The above results suggest that for mansize objects, the magnetically induced current flow within portions of the body may be within the same range as the current flow induced by the electric fields. However, the current flow or current density induced by the electric field is much more uniform throughout the body than is that created by the magnetic field. Near the center of the body, the magnetically induced current should tend to zero (due to the dependence on r in the above equation); thus, the predominant concern for persons within the fields created by EHV transmission lines appears to be with regard to the body currents induced by the electric field.

2.3 Effect of Current and Voltage on Humans

The effect of the fields from EHV transmission lines on persons has generally been approached from two aspects. The first is the psychological and physiological effects caused when a person beneath a transmission line comes into contact with another object that is charged to a different potential. In this case, transient or steady state currents can be caused to flow through the person's body. The time-frame involved in noting these effects is, in general, quite short. That is, if a person contacts an electrified object, and adequate current flows through his body, the indication of this event is immediate. Either he feels a tingling sensation, pain, or a more severe effect such as complete loss of muscle control, permanent respiratory arrest, asphyxia, or ventricular fibrillation.

The only known short-term possible potentially hazardous effect which may be caused by the fields, without requiring the person to come in contact with other objects, is the interaction of the fields with implanted medical devices. These so-called short-term effects will be discussed in this section of the report. The next section of the report will discuss what might be termed long-term effects due to the direct interaction of the transmission line fields with the body. The use of the terminology of "long-term" and "short-term" to permit an orderly discussion of the various effects involved, is somewhat artificial, since some investigators have reported measurable direct biological interaction due to the fields which were apparently below the perception thresholds, yet occurred in short time-frames in coincidence with the application of the fields; for example, see Waibel, 1975.

2.3.1 Direct Psychological and Physiological Effects

For either of the two manners of classifying the effects that have been suggested above, the effect may be due to either transient or steady state current flowing through the body. For many occurrences of contact with electrified objects, both the transient or steady state current effects may occur. However, it is convenient to separate, for discussion purposes, the effects due to transient or steady state currents flowing through the body.

In addition to the short-term effects which may be noted due to contact with electrified objects, the possibility also exists for the direct perception of the fields by a human or animal. This direct perception of the fields appear to fall in the psychological category, but may be important with respect to a person's subjective concern over the presence of the transmission line, or more importantly, as a cue to the presence of the field which may influence the outcome of certain types of biological experiments; for example, if the sensing of the field produces apprehension in the test subject.

In discussing the relative degrees of severity of currents flowing through the body due to contact with electrified objects, the IEEE, 1971 Part 1, has classified the shock currents as primary shock currents, which cause direct physiological harm; or secondary shock currents, which cannot cause direct physiological harm, but may produce involuntary muscular reactions. Bridges, 1976, suggests that a simpler categorization might be:

1. psychological--simple perception, annoyance, and pain;

2. reversible physiological -- involuntary reflexes such as inability to release a clasped current carrying conductor; and

3. potentially irreversible physiological -- burns or ventricular fibrillation.

2.3.1.1 Direct Perception of Fields

Work has been done that provides strong indication that a person can perceive the presence of relatively strong electric fields without the necessity for coming into contact with other charged objects. Early work by Kouwenhoven, et al., 1966, states that a person is barely able to feel a current density of about .078 $\mu A/cm^2$ entering the skin area due to the presence of an electric field. This current density entering the skin surface, corresponds to an electric field at the surface of the skin of approximately 240 kV/m. Due to the manner in which the electric field can be enhanced at the body surface, such a field can correspond to a significantly lower undisturbed electric field intensity. Kouwenhoven states that the sensation is like that of a gentle breeze blowing on the skin.

Deno and Zaffanella, in Chapter 8 of the Transmission Line Reference Book, 345 kV and Above, report on tests performed on a limited number of subjects to assess the direct perception of electric fields. They noted that the most common sensations were hair-nerve stimulation due to hair erection, and tingling between body (particularly the arms) and clothes. More recently, additional statistical data on the human sensitivity to the perception of electric fields has been obtained, IEEE, 1978. These tests were conducted on 130 persons and determined both the perception and annoyance sensations for hand-hair, head-hair, and tingling. The most sensitivity found was with respect to head-hair, where the electric field for perception by 50% of the population was 7 kV/m. At this level of field, approximately one percent of this group were annoyed by the hand-hair stimulation feeling. Approximately 10% of the test group indicated a perception of hand-hair stimulation at a field less than 2 kV/m. The fields here are expressed in undisturbed electric field. For the perception of head-hair and body clothes tingling, the test results were similar to each other, with approximately 10% of the test population noting perception at about 5 kV/m.

In performing experiments with swine, Hjeresen, et al., 1976, observed that the threshold field strengh for piloerection and hair oscillation was about 50 kV/m for the swine, and experimental evidence was obtained that indicated that they perceived the electric field at 30-40 kV/m.

While the above perception and annoyance aspects of the electric field do not appear significant from the biological standpoint, these factors may have significant implications in the design of certain types of human or animal experiments. If the perception of the fields gives rise to apprehension, such apprehension may be evidenced in the experimental results.

Tucker and Schmitt, 1977, have investigated the ability of persons to sense the presence of a moderate (7.5-15 Gauss) alternating 60 Hz magnetic field. They found that elaborate procedures were necessary to prevent perceptive individuals from non-intentionally using subtle auxiliary clues to develop impressive records of apparent magnetic field detection. However when adequate precautions were taken, the analysis of the data showed that these fields are not normally sensed directly. Again, the ability to sense an applied field, either by direct sensation or by subtle cues that the field is present, may be a significant factor in biological experiments with either humans or animals.

2.3.1.2 Transient Currents

Transient currents are encountered when an individual comes into contact with a charged object that is at a different potential than the individual. If the potential difference between the object and the individual are sufficient, a small arc may be established just prior to initial contact. In most cases, this is just a disagreeable event, accompanied by annoyance and possibly some pain. In many respects, these discharge currents are similar to the minor shocks that are experienced on a dry day by a person walking on a rug and then touching a grounded metal object such as a door knob, electric light switch, or elevator call button.

Some of the physical factors which control the nature of a capacitive spark discharge may be better understood by referring to Figure 2.11. This figure represents the approximate equivalent circuit of a person coming into contact with an object such as a vehicle that is charged by electrostatic induction beneath a transmission line. The important factors are the capacitance of the object, the open circuit voltage of the object prior to contact, the time and voltage dependent arc resistance, the other resistances associated with the conduction of current through the body, and the impedance of the soles of the shoes to ground.

The body current during discharge, I_L, as well as the Joule energy transfer, is partially limited by the impedance of the soles of the shoes to ground. This impedance is much higher where thick crepe rubber soles are worn and when dry ground conditions prevail. Under dry conditions, it is likely that the voltage across the vehicle will be greater; this may be mitigated by the higher impedance to ground through the person. Under wet conditions, the person may be better grounded; however, the voltage across the vehicle may also be lowered due to the leakage resistance of the tires to ground.

A simplified equivalent circuit is often used to represent the capacitive spark discharge situation. The charged object is represented as a capacitor which is charged to a voltage, V. Due to the time-varying nature of the electric field, the voltage to which the object is charged is a time-varying function. The person through which the current will flow is represented by a resistance which, under well-grounded conditions, is generally taken as approximately 1500 ohms. At the instant of conduction, the current that flows through the body is given by the ratio of the voltage across the capacitor divided by the resistance through which the current must flow.

This value of current is not sustained, and it rapidly decreases. The current can decrease to about a third of its initial value in times which are less than one microsecond.

Another factor which is often used for assessing the discharge situation is the Joule energy that can be delivered to the body during the discharge. The Joule energy is given by $\frac{1}{2}CV^2$, where C is the capacitance of the charged object, and V is the voltage at the instant when the arc is established or contact is made. For contact with objects charged with 60 Hz voltage, a series of small arcs may be formed at the crest of each 60 Hz half-cycle. Thus, the perception of the arcs is likely to be more noticeable when a slow approach to the object is used.

Stanley, 1976, compares the spark discharge energy from an insulated conducting body in the field of an EHV transmission line to that of static discharges that an individual may receive after walking across a carpet and touching a door knob. He notes that an adult human may build up a potential on his body in excess of 20 kV by walking across a carpet during periods of relatively low humidity. He indicates, however, that it is more likely that the potential will be more in the range of 4-8 kV. Assuming the capacitance of the human body to be approximately 200 pF, and the static charge voltage to be 6.6 kV, he determines the discharge energy to be 4.3 millijoules. Since this is the static case, the discharge will occur only once.

For ideally insulated objects beneath a transmission line, considerably more Joule energy than this can be available. Bridges, 1976, shows that for a 150-meter long ideally insulated fence in an 11 kV/m field, approximately 60 millijoules of stored energy will be available.

For a very large vehicle beneath a transmission line, whose capacitance may be as high as 5000 pF, it is necessary for the voltage on the vehicle to be less than approximately 1000 volts in order that the stored energy be approximately 1000 volts in order that the stored energy be approximately that determined by Stanley for the static door knob case. Perkins and Novak, 1977, have shown that for a variety of objects underneath the line, that if special precautions to well-insulate the vehicle from ground were not taken, the voltage of the vehicle induced by the power line was consistently less than 1000 volts. The objects they studied included some that were quite large, such as a school bus, a tractor-trailer, and farm vehicles. They also conclude that spark discharges from uninsulated vehicles sitting on the ground will be quite small because of the leakage across the tires.

The U.S. Atomic Energy Commission, 1967, indicates a level of 250 millijoules for causing involuntary reflexes. The IEEE, 1971, asserts that the transient currents from charged objects beneath the line are not in themselves considered dangerous, because the period of shock is normally too short to produce ventricular fibrillation. They further state that it is believed that a value of 50 joules should be used as the danger threshold in humans.

The Consumer's Power Company, 1975, in responding to the Federal Register Notice, states that they have tentatively established a 0.1 millijoule as a maximum level for energy discharge from ungrounded stationary objects under or near EHV transmission lines. All stationary objects which could develop an energy level greater than 0.1 millijoule would be grounded. This 0.1 millijoule energy level corresponds to what might be considered the threshold of perception as noted in the Transmission Line Reference Book, 345 kV and Above, 1975. This range of energy is also in substantial agreement with the borderline of perception value of 0.085 millijoule which was determined by G.L. Reiner, 1971. The Consumer's Power Company further suggests, however, that even though spark discharges near the perception level present no hazard, more research and more data on spark discharges is required to determine a statistically acceptable energy discharge level.

2.3.1.3 Steady-State Currents

Although spark discharge effects which may occur under transmission lines may provide some annoyance, it is seen from the above discussion that, in general, these occurrences are not considered hazardous. However, once contact is established, a continuous current flows through the body of the person who may be in contact with the charged object.

It is well recognized, that for large metallic structures located in regions of strong electric fields, potentially hazardous current levels can be obtained from such structures. As previously noted, the power companies, as a matter of policy, provide grounds for those stationary objects which can provide short circuit to ground currents greater than approximately 0.5 milliamperes. This level of short circuit current is consistent with ANSI standards for the maximum allowable leakage current from portable 60 Hz powered devices, such as household appliances. Table 2.5 presents data summarized from available literature by the IEEE, 1971, on the biological effects of thresholds for body current. Since the power companies provide grounding of stationary objects in the near vicinity of EHV transmission lines, the primary concern with respect to potentially hazardous currents from electrified objects centers around movable objects, such as vehicles.

Considerable care must be exercised in construction operations in the vicinity of transmission lines. Particular concern is with regard to stringing adjacent transmission lines or installing pipelines. The IEEE, 1973, has provided an excellent review on the hazards associated with these situations, and the procedures to be used by the construction crews in minimizing hazards. Since these hazards are not normally encountered by the general public, they will not be discussed further here.

Table 2.5

BIOLOGICAL EFFECTS THRESHOLDS FOR BODY CURRENTS AND SHOCKS
(From IEEE, 1971)

Current Criteria				
	Current in Milliamperes			
	Direct Current		60 Hertz RMS	
Effect	Men	Women	Men	Women
1. No sensation on hand	1	0.6	0.4	0.3
2. Slight tingling. Perception threshold	5.2	3.5	1.1[*]	0.7[*]
3. Shock--not painful and muscular control not lost	9	6	1.8[*]	1.2[*]
4. Painful shock--painful but muscular control not lost	62	41	9	6
5. Painful shock--let-go threshold	76	51	16.0	10.5
6. Painful and severe shock muscular contractions, breathing difficult	90	60	23	15
7. Possible ventricular fibrillation from short shocks:				
a) Shock duration 0.03 second	1300	1300	1000	1000
b) Shock duration 3.0 seconds	500	500	100	100
c) Certain Ventricular fibrillation (if shock duration is over one heart beat interval)	1375	1375	275	275

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[*] Similar current levels for "perception" and "annoyance" are presented in a later work by Bracken, T.D., 1975, who also provides such information for children test subjects.

The IEEE, 1971, reviews the available data on the primary shock currents. They note that it is virtually impossible to produce primary shock currents with less than 25 volts, because of normal body resistance. They also note that the most dangerous possible consequence of primary shock current is ventricular fibrillation. They cite the work of Dalziel, and present his electrocution equation, $I = k/\sqrt{t}$; where I is the current level in milliamperes, corresponding to a particular probability of ventricular fibrillation; and where t is expressed in seconds. Examples are provided of the use of this equation to calculate fibrillation current from curves given by Dalziel, 1969, for fibrillating current versus body weight for various animals.

The short circuit current to ground for a large variety of vehicles under worst case conditions, that is, when on insulation, is presented in Zalewski, 1976; Bracken, 1975, and Perkins, 1977. These data show that 10 milliamperes can be considered as an upper bound current. Comparing this level of current to the summary data shown in Table 2.5, and to other data summarized in IEEE, 1971, reveals that the likelihood of ventricular fibrillation for this class of object is very remote. The extreme remoteness of ventricular fibrillation under these conditions is emphasized by the more realistic vehicle current considerations presented by Perkins and Novak, 1977.

For currents to the body, caused by electrostatically charged mobile objects, the primary concern appears to be with respect to let-go currents. The let-go current is defined by Dalziel, 1969, as the maximum current at which a person is still capable of releasing a conductor by using muscles directly stimulated by that current. Dalziel further points out the importance of the let-go threshold by noting that an individual can withstand, without serious after effects, repeated exposure to his let-go current for at least the time required for him to release the conductor. The Dalziel data show that 99.5% of women have a let-go threshold greater than 6 mA, while 99.5% of the men have let-go thresholds larger than 9 mA.

Adequate data are lacking on the let-go thresholds for children. This threshold has been estimated to be in the range of 4.5 - 5.0 mA (Stanley, 1976; Simpson, 1977), and 4 ma (Lyskov, 1975). The National Electrical Safety Code specifies 5 mA as the maximum allowable short circuit current for the largest vehicle expected beneath a transmission line.

However, there are some (e.g., Hackenberry, 1974), who believe that since there is no direct evidence available for the response of children, that the safe let-go current for small children may be in the 3 mA range. It therefore appears that although many accept, at face value, the let-go levels determined by Dalziel for men and women, the lack of data applicable to children prevents good agreement for this situation.

In his review of the literature on let-go current thresholds, Bridges, 1976, notes that the Dalziel data may not be directly applicable to the situation which exists beneath the power transmission lines. He concludes that the experimental procedures used by Dalziel will have a tendency to produce let-go thresholds that are unrealistically low. Dalziel, 1969, notes that higher let-go thresholds were observed in connection with friendly wagers between the students being tested. This suggests that higher let-go thresholds might be applicable if a person felt his life might be in danger if he did not let go.

Bridges also points up two other factors relating to the Dalziel experiments which are different than for contact to an electrified vehicle, for example--beneath a transmission line. First, the experiments were conducted with the subjects grasping a small conductor while the current was increased through the conductor to a point where the subject could not release the conductor. Bridges conjectured that as the voltage and current were progressively increased, the resistance of the skin during any given test had an opportunity to decrease so long as the contact was maintained. Dalziel notes the human tissue has a negative resistance characteristic, such that the body resistance decreases with both increasing current and with increasing time of contact. If an object is grasped while at voltage, the normal response to let go may occur before the skin resistance decreases to the point where sufficient current to prevent let-go occurs.

Bridges also points up that the direct application of let-go values found in the literature, does not take into account the precursor spark discharge which is likely for the transmission line situation when the current available to the body is in the let-go range. Thus, the subject is likely to release the object before firm grasp is obtained, due to the transient discharge which occurs before contact to the object is made.

It thus appears that adequate data does not exist with regard to small children and their let-go thresholds. It also appears that while statistical data exist on the let-go thresholds for men and women subjects, these data may not be applicable to the practical situation. The existing data may not realistically consider the precursor spark discharge, the time dependence of body impedance, and the psychological motivation of the person to let go, thus resulting in published current levels which are too low.

2.3.2 Implanted Medical Devices

Concern has been expressed over the possibility of electric or magnetic fields that are produced by power transmission lines interfering with the operation of implanted medical devices. Driscoll, 1975, considered the current which might be collected by a large metallic plate (10x10 cm) proximal to the cortex of the brain (replacing a portion of the skull). He concluded that the current collected by such a plate would be considerably less than that required for neural stimulation. However, no specific research has been conducted to determine the effects on such medical devices which might result from the influence of fields from transmission lines.

With regard to implanted medical devices, the primary concern has centered around the possible interference effects to implanted cardiac pacemakers. Although the subject of interference to implanted pacemakers was included in the testimony of Driscoll, 1975; Toler, 1976; and Michaelson, 1976, before the New York State Public Service Commission, their testimony did not have the benefit of the most recent work on this subject, which was still in progress at that time.

Bridges and Frazier, 1976, have recently completed a study of the effects of 60 Hz electric and magnetic fields on implanted cardiac pacemakers in humans. The results of that study form the basis for the discussion which follows.

Prior to the work of Bridges and Frazier, there were two previous important studies on the interference to cardiac pacemakers by 60 Hz fields. The first, by Miller, 1971, was an evaluation of the effects of magnetic field interference. In this study, pacemakers implanted in calves were used to study the effective coupling between the magnetic field and the pacemaker. Procedures were developed to predict magnetic field interference thresholds for pacemakers based on interference voltage thresholds.

A study by Zalewski, 1975, provided a preliminary assessment of electric field interference effects. In this study, bench tests on pacemakers and surface measurements on humans resulted in a preliminary understanding of the level of electric fields which could cause effects on pacemakers.

The development and widespread use of implantable cardiac pacemakers has been a significant advance in the treatment of heart disorders. About 50,000 of these small electronic units are implanted into patients annually, and over 170,000 pacemakers are now in use in the United States. Since many pacemaker patients can resume nearly normal lifestyles after the implantation, they encounter the same wide range of electromagnetic environments as the general population.

A cardiac pacemaker is an electronic device which can stimulate the heart with periodic electrical current pulses to maintain rhythmic heart contractions. Some pacemakers produce pulses that are synchronized to a particular portion of the natural cardiac signal. These are called synchronous pacemakers. Others produce regularly spaced pulses that are independent of, or asynchronous with the cardiac cycle. These pacemakers are called asynchronous. However, by far the most widely used type of pacemaker senses a particular segment of the cardiac signal, the R-wave, and produces stimulus pulses only when the normal heart beat slows or stops. This type of pacemaker is called variously the R-Wave inhibited, or standby, or demand pacemaker. If a demand pacemaker senses electric signals or interference from other sources which may mask the heart's signal, the pacemaker begins to operate in the "asynchronous mode." This means that regularly spaced pulses, which are not synchronized to the cardiac cycle, are produced, even though the patient's heart may be functioning normally. Some cardiologists feel that this situation should be avoided, though cardiologists do not agree on the existence or extent of risk. Michaelson, 1976, is of the opinion that reversion to the fixed rate will generally not cause cardiac problems; and, that in those few patients where problems might occur, the results would generally not be serious.

This asynchronous mode of the demand pacemaker may be triggered if an induced interference voltage develops across the tissue between the pacemaker electrodes. Since body tissue is resistive, any current flowing through the body will cause a voltage to develop across tissues. If this tissue voltage is large enough, the pacemaker will "revert" to the asynchronous mode.

Weak body current can flow when a person touches an electric device, such as a household appliance, tool, or machine. Weak body current can also be caused by the electric and magnetic fields from energized conductors, such as power lines. These fields cause body current to flow even if a person is not touching a conductor or electrical device. An understanding of the relationship between these fields, body current, and pacemaker response is required to evaluate the possibility of electric fields affecting implanted pacemakers.

Bridges and Frazier, 1976, developed procedures to determine the voltage produced between the electrodes of implanted pacemakers by body currents and electric fields, then demonstrated that effects on the pacemaker operation resulted from these voltages. Thresholds of body current and electric fields capable of affecting normal pacemaker operation were determined for realistic conditions.

Thirteen current model pacemakers from three manufacturers were bench tested to characterize their performance, as a function of 60 Hz voltage level applied to their terminals. These tests included the determination of the threshold for reversion to the asynchronous mode. Six implants were made in baboons, using pacemakers selected from the group that were bench tested. The effects of both electric fields and body currents on pacemaker reversion were determined by in vivo experiments with these animals.

Data from animal tests were used to relate internal and surface voltage to body currents. Based on this relationship, the voltage across implanted pacemaker electrodes can be determined from skin measurements. Field strengths at which implanted pacemakers revert were measured by exposing baboons with implants in a high voltage facility. The model was validated by comparing these values with those calculated using reversion threshold data from bench tests.

To adapt this model to the human case, skin measurements were made on four (4) volunteer human subjects. The data reported here are based on calculations using this model and assuming a man of average dimensions.

The field or body current necessary to cause pacemaker reversion is highly dependent on the type of pacemaker and location of the implanted electrodes.

The bench tests showed that reversion thresholds ranged from a "least sensitive" value of 12 millivolts to a "most sensitive" value of 1/2 millivolt with a "typical sensitivity" being somewhat less than 1 millivolt.

Table 2.6 presents calculated examples of 60 Hz electric fields which would cause pacemaker reversion for representative pacemaker sensitivities and electrode separations. These calculations assume a well-grounded person standing erect in the field. For reference, Table 2.1 presented common ranges of near-ground electric fields for transmission lines of various voltage ratings. These examples indicate that electric fields from 60 Hz extra high voltage (EHV) transmission lines, as they exist in the United States today, are unlikely to interfere with the majority of pacemaker patients. The examples suggest, however, that some pacemaker patients may experience pacemaker reversion to the asynchronous mode under some field conditions. Electric fields large enough to cause pacemaker reversion only occur directly beneath EHV transmission lines. Thus, cardiac pacemaker patients living in suburban and urban areas would rarely be exposed to such fields, especially for long periods of time.

Table 2.7 presents calculated values of 60 Hz magnetic flux density required to produce reversion in pacemakers of various sensitivities under worst case electrode configuration. Since the near-ground magnetic flux density of power transmission lines operating at the highest voltages found in the United States is usually less than 1/2 gauss, Table 2.7 shows that pacemaker interaction problems by magnetic fields are unlikely.

Table 2.8 shows the levels of 60 Hz body current flowing axially through the thorax which is calculated to cause reversion to the asynchronous mode for different combinations of pacemaker sensitivity and electrode separation. Such current flow can be caused by leakage from appliances, machines, and

Table 2.6

ELECTRIC FIELDS FOR R-WAVE PACEMAKER REVERSION

(calculated example)

	Lead Arrangement*		
Pacemaker Sensitivity	(2.5 cm) Bipolar	(8.3 cm) Monopolar Pectoral	(14.5 cm) Monopolar Abdominal
12 mV	600 kV/m	171.0 kV/m	91.0 kV/m
1 mV	50 kV/m	14.3 kV/m	7.6 kV/m
0.45 mV	23 kV/m	6.4 kV/m	3.4 kV/m

Table 2.7

MAGNETIC FIELD FOR R-WAVE PACEMAKER REVERSION

(calculated example)

Pacemaker Sensitivity	Magnetic Field With 210 cm^2 Worst-Case Loop
12 mV	15.0 gauss
1 mV	1.25 gauss
0.45 mV	0.56 gauss

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*Vertical electrode separations used for example are shown in parentheses above each lead configuration.

Table 2.8

CURRENT NECESSARY FOR R-WAVE PACEMAKER REVERSION (in μA)

(calculated example)

	Electrode Separation		
Pacemaker Sensitivity	2.5 cm	8.3 cm	14.5 cm
12 mV	6000	1800	1000
1 mV	500	150	88
0.45 mV	230	70	40

Table 2.9

ELECTRIC FIELD FOR R-WAVE PACEMAKER REVERSION DUE TO VEHICLE LEAKAGE CURRENT

(calculated example)

	Electrode Separation/Pacemaker Sensitivity		
Vehicle Type	2.5 cm/12 mV	8.3 cm/1 mV	14.5 cm/0.45 mV
Compact	68.0 kV/m	1.7 kV/m	450 V/m
Sedan	60.0 kV/m	1.5 kV/m	400 V/m
Camper	21.0 kV/m	500.0 V/m	140 V/m
Semi-Tractor Trailer	8.6 kV/m	200 V/m	60 V/m

tools. Published leakage current data for some appliances and present day standards for portable appliances, which limit leakage currents to 0.5 mA, surpass some of the values given in Table 2.8. However, appliance leakage currents will flow through the body only if the appliance case is ungrounded and the person completes the path to ground by touching the appliance.

Patients with monopolar lead implants may be more likely to experience reversion from appliances in the home than from exposure to above ground transmission lines, but circumstances leading to prolonged reversion by either cause are probably rare.

When one touches an ungrounded conducting object, such as an automobile, tractor, or truck, that is near a transmission line, currents of about the same magnitude as appliance leakage currents can flow through the body. Such currents vary widely due to weather conditions, type of footwear, and other factors. Table 2.9 shows the electric field intensities which would induce large enough currents from typical vehicles to cause reversion for various pacemaker sensitivity and electrode separation combinations. Tables 2.1 and 2.9 show that under worst-case conditions, the fields from nearly all transmission and distribution lines may cause enough current to flow from a large insulated vehicle to cause pacemaker reversion if the vehicle is touched. Again, conditions which would cause prolonged reversion are probably rare.

Bridges and Frazier conclude that there are several ways to minimize risks for pacemaker patients who might be susceptible to fields from overhead transmission lines or current from household appliances. The most promising option is the use of pacemakers which are intrinsically insensitive to 60 Hz voltage or to use implantation lead arrangements that are least sensitive to body current.

Improved pacemaker designs are available and insensitive lead arrangements are now often used. Thus the cardiologist, who has the choice in selecting pacemaker and implants, can now ensure negligible patient risk due to a broad range of common 60 Hz field environments.

While a solution to the problem appears to be achievable, involved parties including the patient, manufacturer and medical practitioner must recognize the importance of factors within their control. The cooperation and awareness of these parties is essential. The research results presented by Bridges and Frazier provide basic information needed for this awareness.

2.4 The Direct Effects of Fields on Living Organisms

2.4.1 Background

Man has always been exposed to the electric and magnetic fields arising from nature, and has been exposed to the 60 Hz fields produced by electrically operated man-made devices for many years. However, with the widespread growth in EHV power transmission systems and the study of ELF communications, there has been an increasing interest in the effects that such fields might have on living organisms.

Concern over the possible deleterious effects of electromagnetic energy on biological systems is not new. With the development of extensive radio frequency communication systems and radar, during the second World War, the Department of Defense became interested and concerned about possible hazards associated with radio frequency emitting electronic equipment. The concern over the hazards associated with human exposure to such radiation, generally termed non-ionizing radiation to distinguish it from the radiation from nuclear material, has resulted in a considerable body of research to investigate these effects and hazards. However, the effects of non-ionizing radiation from electronic equipment (see Michaelson, 1972, for a review of this work) is generally recognized as having little relationship to biological effects which may occur as a result of exposure to fields at the frequency of power lines.

The questions that have been raised concerning possible biological effects of power line and ELF communication fields, thus have not been directly answered by application of the body of knowledge existing for fields at radio frequencies and above. In recognition of the concern with regard to the biological effects of extremely-low-frequency electromagnetic fields, considerable research has been conducted over the past several years in an attempt to understand the interaction of ELF fields with life forms, and to identify any hazards which may exist.

Since extremely-low-frequency electric and magnetic fields from both natural and man-made sources have provided an exposure to man for a considerable period of time, it is likely that if any effects are present, they are subtle.

Representatives of the power industry, for example, Cohen, 1976, and Barnes, 1976, cite the long experience of power companies in using HV and EHV power transmission systems as an indication that there are no deleterious effects on living organisms. The lack of indication of biological problems, either to the public or to power utility personnel, as a result of existing lines has a definite bearing on research conducted to investigate possible hazards associated with such exposures. Thus, if effects do occur, they may be long term, and not readily observable or evident. The apparent lack of problems associated with existing transmission systems was not adequate to answer the specific questions of many with regard to the development of higher voltage transmission systems or ELF communication systems. Also, reports from the U.S.S.R. on neurological effects on switchyard workers provided a direct stimulus for research into possible hazards of ELF electromagnetic fields.

2.4.2 Range of Research

The research into biological effects of extremely-low-frequency fields has been quite wide-ranging and diverse. Hundreds of articles have been published, dealing with one aspect or another of the topic. Research has been conducted using a wide range of test subjects exposed to a variety of electromagnetic field conditions, and the biological parameters monitored have been many. With so much research being conducted, it is not surprising that conflicting results have been noted. The implication of the research results with regard to a likely hazard is not always evident. The manner in which specific research results should be applied to the practical situation is also not well understood or evident. In view of these factors, as well as the concern of many over the quality of the research, it is not surprising that considerable controversy and difference in opinion exists. The following paragraphs will present a brief overview of some of the facets of the research that has been conducted.

2.4.2.1 Range of Subjects Studied

Various test subjects have been used in conducting experiments into the effects of ELF fields. Some of the test subjects have been chosen because of direct concern for the influence of such fields on the particular biological subject. Most concern resides in the possible influence of these fields on man. In the United States, only limited investigations into the effect of ELF fields on man have been conducted. Investigations using man as the subject appear to be principally limited to those of Beischer, 1973; Busby, 1974; Kouwenhoven, 1967; and later Singewald, 1973. However, foreign investigators have reported additional field and laboratory studies where man was the test subject.

Concern over the effects of ELF fields on other specific biological organisms in nature has prompted the study of birds, fish, tadpoles, turtles, soil microorganisms, earthworms, slugs, and a variety of plant forms. In addition, much research has been conducted using test subjects that are convenient or more well suited for laboratory biological investigations. These subjects include rats, mice, dogs, monkeys, fruit flies, chickens and eggs, and a variety of plant forms. Thus, investigations have been conducted into a large variety of different types of life forms, in an attempt to determine if any effects are noted due to exposure with ELF fields.

2.4.2.2 Range of Effects Studied

The effects studied in experimental investigations usually fall into one of several areas. A given experiment on a given type of test subject, may investigate more than one of these effects categories. However, the various effect categories are often individually discussed in an attempt to identify common effect trends across different biological subjects. The effects most often investigated are: genetics, fertility, growth and development, physiology, biochemistry, behavior, circadian rhythms, ecology, and epidemiology. As noted, a study to investigate a particular effect, for example, fertility or growth and development, may utilize any one of a number of test subjects. In addition, different experimental procedures may be used by different investigators to study the same effect on the same test subjects. Thus, it is often difficult to relate the results of two different experimenters investigating the same effects due to differences in the basic experimental design and in the parameters monitored.

2.4.2.3 Range of Field Parameters

The basic thread of the research investigations of concern are the effects of extremely-low-frequency electromagnetic fields, or the concomitant currents that arise from such fields on biological organisms. It is often desired to assess the impact of a specific system, e.g., a 765 kV transmission line. Since much of the work that has been conducted has not been for the purpose of evaluating the potential hazards associated with the fields of such a line, it is not always evident how such research results apply. That is, the purpose of the research influences the manner in which the experiments were conducted. This is particularly true with regard to the electromagnetic field parameters.

Research stimulated by interest in power line fields will typically use an electric field exposure of the test subject. The frequency of the field used is normally 60 Hz. Some experiments have considered the magnetic field, and thus simultaneously apply such a field component to the test subject. These differences in experimental procedures with regard to the electric field parameters may be significant, since the magnetic field from a fully loaded power line can induce current flow within humans that is spatially different than the induced current distributions from the electric field.

Experiments that have been conducted to investigate the biological effects of Seafarer, the Navy Communications System, use fields that are related to the specific nature of that system. For that system, low horizontal electric fields are anticipated; however, the magnetic field is in the same range as observed from power lines. Thus, many experiments that have been conducted to answer biological questions with regard to the communication system, have used only a magnetic field exposure. Since this system does not operate at 60 Hz, some of the experiments have used a frequency closer to the eventual operating frequency, which is about 76 Hz. In addition, since this system will be modulated, questions have been raised on the effects of such modulations; therefore, some tests have been conducted using representative modulations.

In Europe, the power frequency is 50 Hz rather than 60 Hz. Thus, research conducted in Europe to assess the effects of power line fields have utilized the frequency of 50 Hz. It is unknown whether or not organisms are sensitive to changes in frequency over the range of 50-76 Hz; however, for the same electric or magnetic field, 50% more current will be induced into a test subject at 76 Hz than at 50 Hz.

In addition to research being conducted for specific man-made systems, a considerable body of literature has been generated in an attempt to understand the influence of the static or the natural geomagnetic fields on man. The frequencies used in this research can be as low as 1 Hz or less, but typically is in the range of 10 Hz. Signals that are recorded from the brain are in this frequency range, and thus this frequency range appears to be of special interest for certain research groups.

Yet another area of study which has produced research results is investigation into the use of electricity for therapeutic or diagnostic purposes. Generally, these investigations induce current flow into the body by means of galvanic contacts (direct wire connections). The frequencies used in this work can vary considerably, and often includes dc.

In addition to the field-type and frequency variables, the level of excitation is also an important parameter. Here, the level of excitation is likely to be related to the basic purpose of the research. Thus, for example, electric fields used in the published research can range from a fraction of a volt/meter to hundreds of thousands volts/meter. Similarly, experiments have used magnetic fields ranging from a fraction of a Gauss up to several thousand Gauss.

Another factor which may make it difficult to relate one experiment to another is the exposure time. The U.S.S.R. has promulgated rules and regulations for workers in substations and beneath overhead transmission lines; see "Rules and Regulations on Labor Protection at 400, 500 and 750 kV AC Substations and Overhead Lines of Industrial Frequency (in the U.S.S.R.)," 1971. These rules and regulations, reproduced here as Table 2.10, not only stipulate field level, but also the permitted duration of exposure, which is a function of the field intensity. The implication here is a dose-related effect. Thus, the exposure duration in experiments to assess biological hazards may be an important parameter. Exposure times noted in reported research are found to vary from a few minutes to months. Disagreements in comparing the results of two investigators' work have been noted due to the different time spans over which the experiments were performed.

Table 2.10

U.S.S.R. FIELD EXPOSURE RULES FOR SUBSTATION WORKERS

Nos.	50 Hz Electric Field Intensity kV/m	Permissible duration of personnel stay in electric field during 24 hours (minutes)	Notes
1.	5	unlimited	Points 2, 3, 4, and 5 of the regulations are valid if: 1) all the remaining time a man is in areas where electric field intensity is less than or equal to 5 kV/m 2) a possibility of electrical discharge influence is eliminated.
2.	10	180	
3.	15	90	
4.	20	10	
5.	25	5	

Additional Notes on Table 2.10:

1) The discussion of this table in "Rules and Regulations...1971" states that if the intensity of the electric field at the working site is not equal to the standard values (shown in the above table), the permissible duration that a person may be in the electric field must be determined according to the next greater value of intensity. Interpolations in the table are not permitted.

2) It is not clear from this reference what remaining exposures are permitted after a shorter duration stay than specified for a particular field range; e.g., questions such as the following are apparently not answered by the referenced document. After an exposure of 10 minutes at 10-15 kV/m, how long can the person work in a field of 5-10 kV/m?

2.4.3 Experimental Control in ELF Biological Experiments

2.4.3.1 Test and Control Subjects

The purpose of the biological experiments of concern is to determine whether or not an ELF electromagnetic field stimulus has an effect on the biological organism under study.

The manner in which most investigators determine whether or not the electromagnetic field produces an effect is to use two groups of test subjects--only one of which is exposed. Thus, if the biological parameter being monitored differs between the two groups in a statistically significant manner, then the difference is attributed to the field exposure. A prime requirement of such an experiment is that the stimulus being used, i.e., the electric or magnetic field, is the only thing that differs between exposed subjects and control subjects. In order to make a valid comparison between test subjects and control subjects, the conditions for each must be identical. The manner in which the subjects are handled and their complete environment other than the stimulus to be tested are included.

Several experiments which have been reviewed by a peer group, have been criticized for lack of adequate control subjects. For example, experiments have been criticized when the test subjects did not receive the same amount of light, heat, water, or other normal environmental factors as the control subjects. Some epidemiological studies have been similarly criticized, when the control subjects performed different types of work functions than the subjects exposed to electric fields; for example, the physical exertions were different in the two groups.

The concern over the maintenance of a common environment for both the test and control subjects has raised questions of maintaining the same geomagnetic environment for the control and test subjects. For example, when test animals for an electric field experiment are placed in a cage with metal ceiling and floor, but the control animals are placed in a non-metallic cage, the exposure to the two groups by the earth's electric field will be different. Since some investigators have noted subtle influences that may be due to the earth's electric field, questions may be raised on the results of such an experiment. In experiments using low level ELF fields, questions also have been raised with respect to the possibility of co-existing electric fields from, for example, electrical equipment within the laboratory, which may provide a different stimulus for test and control subjects.

2.4.3.2 Field Simulation Considerations

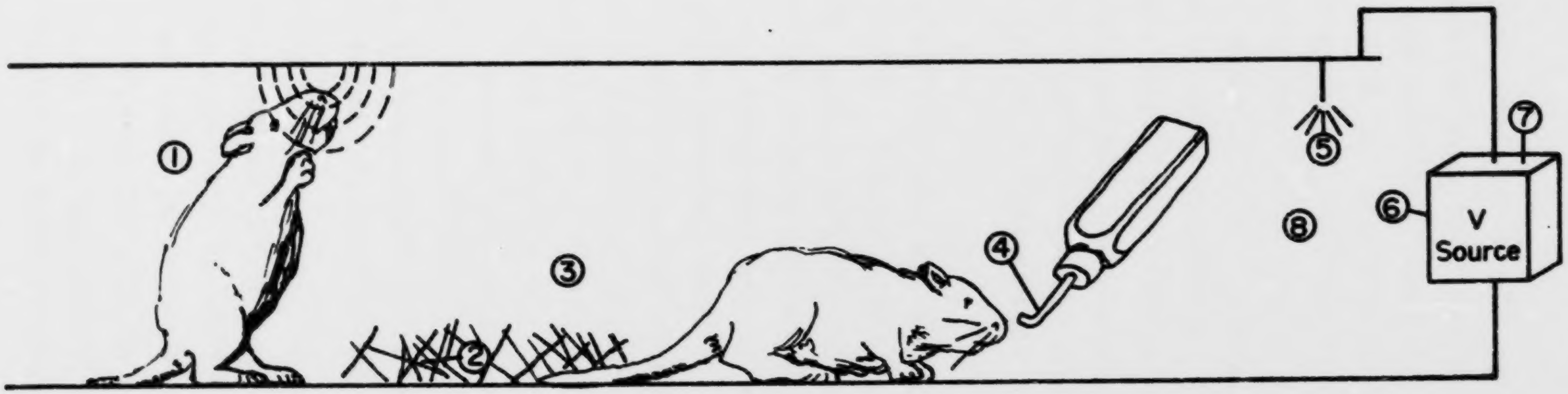
The experimental control factors noted above primarily deal with insuring that the natural factors involved in the environment are the same for exposed and control subjects. The following discusses several aspects of experimental control from the standpoint of producing the electromagnetic field environment to which the test subjects are to be exposed.

For laboratory investigations into the effects of electric or magnetic fields on biological organisms, various field generating structures are used to simulate the power line fields. Normally, laboratory production of the electric fields is accomplished by the use of a parallel plate structure. The test subject--animal, plant, or human--is situated between two metal plates of appropriate dimensions. The metal plates are arranged to be parallel to each other, and separated by a distance d, in essence forming a parallel plate capacitor. When a voltage is applied across the two plates by a suitable source of electrical energy, a field is established between the two plates. The nominal field produced is the voltage impressed on the plates divided by the distance separating the plates.

In many experiments, the reported field exposure level was obtained by just dividing the voltage impressed across the plates by the plate separation, without measuring the electric field in the space between the plates. In Section 2.1, it was shown that several precautions must be employed to assure that the field between the plates is a reasonable approximation to this simple relationship, which ideally only holds for plates of infinite extent. Objects placed in the area between the plates can severely distort the field. Depending on the particulars of the arrangement, highly nonuniform fields may exist, with regions having considerably less or considerably more field than anticipated from the above simple relationships.

If care is not applied in designing the test setup for experiments utilizing relatively high field levels, there is the possibility that corona may be produced due to high field gradients existing at, for example, sharp corners or protrusions. If corona is produced, there is the potential for a buildup of ozone in the test chamber. High concentrations of ozone may affect the biological response being monitored. If a biological response to high ozone concentrations is interpreted as a direct response due to the fields, an erroneous conclusion has been drawn. Similarly, the electric field may modify the air ion distribution within the test chamber. While the biological implication of air ions is controversial (Anderson, 1972; Krueger, 1972), they should not be ignored if noted effects are being attributed to the electric field exposure.

There are several other factors associated with performing electric field exposure experiments, which can influence the outcome of the experiment and provide an erroneous indication of a field-dependent effect. Several of these factors are illustrated in Figure 2.16. The results of several research works have been questioned by reviewers as a result of the investigator not adequately addressing some of the problems identified in Figure 2.16.



1) Substantial increase in Dose While Erect
2) Possible Field Assisted Decomposition of Litter
3) Field Distortion by Litter
4) Arc Discharge From Water Bottle
5) Corona Discharge
6) Possible Oil Vapors From Field Source
7) Magnetostriction Subsonic Noise From Transformer
8) Air Conductivity Alteration

Fig. 2.16 LABORATORY TEST PROBLEMS

In addition to the potential problems noted above with regard to the plate size, which can produce fields different than anticipated, an additional problem is illustrated with regard to the spacing of the field plates. If there is insufficient spacing, a rat or mouse can stand erect beneath the plates and collect considerably more displacement current than it would otherwise collect in a free-field exposure, for the same posture. To prevent problems of this nature, the plate spacing should be at least three times greater than the height of the rat when standing erect.

The presence of litter can not only alter the field intensity between the excitation plates and the top of the litter area, but also can cause localized high field intensities in tiny areas within the litter. The water bottle can also be electrified and thus induce minor arc discharges into the test animals, even though an insulated water bottle is employed. These discharges will tend to inhibit the animal from drinking water, and the reduced water intake may cause adverse biological effects. Other effects which might alter the outcome of the experiment include audible noise or vibration produced by either the fields acting on the chamber, or by magnetostriction effects within the transformer used to develop the voltage across the plates.

Other effects which may influence the outcome of particular types of experiments include the direct sensing of the fields, or knowledge of the presence of the fields due to some secondary cue. Such effects may cause anxiety in the test subject; and while such anxiety is a result of the field presence, it cannot be attributed to the currents flowing in the body directly producing an effect.

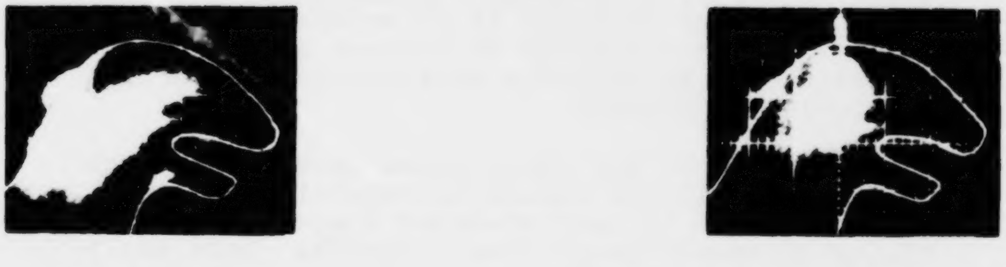
Some experiments include the assessment of biological functions which can be monitored electrically. Included are experiments in which the influence of fields on a subject's EEG or ECG are being investigated. Such experiments often include electrodes that are attached or implanted into the test subject. Often the electrical leads connecting the test subject to the monitoring equipment remain in place during the field exposure. These leads can collect current and enhance or distort the fields within the biosystem or the test chamber.

Guy, 1974, has experimentally demonstrated the profound effect of electrodes attached to the head of a cat during field exposure. During microwave illumination of the cats, he showed that attached electrodes resulted in a complete shift in the internal power absorption pattern and two orders of magnitude increase in the absorbed power near the electrode. This pattern shift is illustrated in the thermograms shown in Figure 2.17 of a cat's head with and without an implanted electrode. Since the thermograms that are shown were obtained for microwave exposures, identical results cannot be expected at ELF; however, in both frequency ranges electrodes attached to test subjects should be avoided during field exposure.

Exposed wires can have current induced on them by either ELF electric or magnetic fields. If such wires are attached to the test subject, the interpretation and implication of the test results in terms of quantifiable parameters such as the field, become very difficult. In reviewing the literature, experiments have been noted where the investigator had considerable difficulty in eliminating the effects of signal pickup in subject-attached wires. The difficulty was noted in connection with monitoring and recording the biological signal of concern. However, these same investigators were not concerned by the added current that might have been induced into the test subject as a result of the attached wires.

2.4.3.3 Biological Design

In addition to the above noted potential problem areas associated with the conduct of experiments to determine the biological effects of electric or magnetic fields, there are several factors associated with the biological design of



(A) No Electrode

(B) With Electrode

Fig.2.17 THERMOGRAPHIC STUDY OF THE EFFECT OF COAXIAL ELECTRODE ON MICROWAVE ENERGY ABSORPTION PATTERNS (COURTESY DR. A. GUY)

experiments, which can result in an experiment being questioned. The National Academy of Sciences, 1977, in reviewing the results of many research programs, has consolidated several specific points which blemish the results of many reported investigations. The points they noted include:

- The sensitivity of the experiment should be adequate to insure a reasonable probability that an effect would be detected if it existed. This point includes a variety of factors among which is the use of an adequate size population for the particular experiment.
- The experimental and observation techniques, methods, and conditions should be objective. Blind scoring should be used whenever there is a possibility of investigator bias; likewise, data analysis should be objective.
- If an effect is claimed, the results should demonstrate it to an acceptable statistical significance by application of appropriate tests. (Author: The same may be true if an effect is not claimed.)
- A given experiment should be internally consistent with respect to the effects of interest.
- The results should be quantifiable and susceptible to confirmation by other investigators. In the absence of independent confirmation, a result has been classified for the purpose of the Committee on Biosphere Effects on ELF Radiation of the National Academy of Sciences, as preliminary.

The above discussion has been provided to convey an awareness that there are many interdisciplinary aspects to the conduct of experiments involving biological organisms and electromagnetic fields. Hylten-Cavallius, 1975, provides additional discussion on the care that must be observed in the conduct of such experiments.

Since a variety of factors which have been noted above can influence the outcome of a specific experiment, extreme care must be exercised in implicating a specific stimulus to the noted response. It is of the highest importance to establish whether biological effects which might be termed hazardous arise from exposure to ELF fields. However, attributing the effect to one stimulus when it is due to another, or due to poor experimental planning, provides no useful information. Similary, if biological interactions do occur but are not noted due to these same errors, the research has done no service.

2.4.4 Major Reviews of Published Research

The Federal Register Notice resulted in the submission of several publications dealing specifically with the biological effects of electric fields. These submissions included published papers or reports which addressed specific experimental results or surveys. These submissions will be discussed in the next section.

Since the time when submissions were made in response to the Federal Register Notice, several important reviews have been published that deal with the effects of ELF fields on organisms. Of special significance are the works published by Bridges, 1975; Shepard and Eisenbud, 1977; National Academy of Sciences, 1977; and the Seafarer ELF Communication System Environmental Impact Statement Appendix E, 1977.

These four review works are particularly significant in that the authors, in reviewing specific research works, have not accepted the conclusions of the reporting investigators at face value. Thus, these four works are not just surveys of published experimental results, but provide critiques for the purpose of pointing up deficiencies in experimental protocol or reporting which may make questionable the original investigators' stated conclusion. Combined, these four publications address virtually all the important research that has been conducted on the subject through at least the 1975 time frame, with many key publications being included in 1977.

Due to the extensive nature of these four works, and their comprehensive coverage of the significant biological research that has been conducted, this present report will not attempt to duplicate this coverage. Instead, a brief overview of each of these works is given in the following paragraphs, along with the essence of the conclusions stated by these reviewers.

- Bridges, 1975, Biological Effects of High Voltage Electric Fields.

This work was based on the review of approximately 800 U.S. and foreign papers pertaining to biological effects of electrical fields at power line frequencies. The report specifically references over 90 citations. A separately bound bibliography includes some 800 citations which were reduced from a reference list of some 2300 citations.

The report describes the electromagnetic environment associated with EHV power lines, and compares these to the natural electromagnetic environment. Also, colateral and cofactor environments as well as dosimetry and experimental protocol are discussed. A detailed review of the literature is provided, with the material being organized in the following topical areas:

- AC electric field tests on humans
- AC electric field animal tests and studies
- horizontal electric and general magnetic field studies
- arc discharges via electrification
- medical devices
- fields from HVDC lines

The author also provides a detailed description of a suggested short-range research plan as well as a long-term plan. The author concludes:

> Although the great bulk of evidence suggests that there are no significant biological effects of electric fields encountered under extra-high-voltage lines, further research is needed. Such research will be difficult and must be carefully done because the need is to uncover any subtle effects, to prove a negative hypothesis, and to assure that transmission technology does indeed protect the public welfare. This report, on the considered recommendations of a workshop comprised of qualified consultants, identifies and sets priorities for needed research in this area. The research plan identifies 23 specific projects which are presented in detail.

- Shepard and Eisenbud, 1977, Biological Effects of Electric and Magnetic Fields of Extremely-Low-Frequency.

This reference text, which is probably the first of its kind appearing in the English literature, provides an excellent summary and review of past work and an excellent introduction to this particular subject matter. Slightly less than half of the text space is devoted toward the discussion of the environment and electromagnetic coupling phenomena. The latter half of the book is devoted toward a critical review of the literature available up until early 1976. This work is also noteworthy for its completeness and objectivity, and because research reports are included that the authors often regard as overly speculative or of less than satisfactory quality. However, these are included for the sake of completeness and objectivity. A total of nearly 400 references are separately cited, but with some duplication. In addition, the authors provide a tabulation of reviewed papers, noting the field conditions, test subjects, noted effect, and author.

In the foreword, the authors conclude the following:

> It would have been satisfying to be able to state that this review, which covers several hundred publications from many countries and from journals of many disciplines, enables one to describe exactly and unequivocally, the health implications of human exposure to low frequency electric and magnetic fields. Regrettably, this is not possible: there is no evidence that the public health or ecological systems have been jeopardized in the slightest by artificial electromagnetic fields. But, there are still stones unturned, and additional studies must be undertaken before it will be possible to state with finality that the matter is closed.

- Navy Electronics System Command, Seafarer ELF Communication Systems Draft Environmental Impact Statement for Site Selection and Test Operations Appendix E, Biological and Ecological Information, February 1977.

This document is part of the much larger group of documents which concern the environmental impact of the Seafarer ELF Communication System. Specifically addressed are the electric and magnetic fields relevant to Seafarer including frequencies of 0-300 Hz, and electric and magnetic field strengths up to 100 V/m and 20 G, respectively. The reported research includes a survey of scientific research which is well-based as well as research results which apparently are preliminary or tenuous. In addition to purely field effects, some conduction and medical electronic aspects are also considered. Persons interested in transmission line field effects will find this document of interest because of its very thorough treatment of magnetic field effects at power frequencies, and because some purely electric field studies at intensities much higher than that intended for Seafarer are also considered. Three hundred references are noted.

While detailed conclusions are presented, the general conclusions are as follows:

> Although research to date does indicate the existence of some rather diverse and subtle effects associated with particular types of ELF exposures, no significant adverse biological effect has been substantiated, or is considered probable from Seafarer System Operation. On the basis of the review of evidence available, it is concluded that:
>
> No significant adverse effects on human health or performance associated with Seafarer exposures has been predicted or substantiated;
>
> No significant adverse effect on human ability to use the environment for livelihood has been substantiated;
>
> No significant adverse effect on human ability to use the environment for recreation has been substantiated;
>
> Research to date indicates it is highly improbable that Seafarer Operation will produce significant and long-lasting biological or ecological effects detrimental to the posterity of the earth's biological systems.

- National Academy of Sciences, Committee on Biosphere Effects of Extremely-Low-Frequency Radiation, 1977, Biological Effects of Electric and Magnetic Fields Associated with Proposed Project Seafarer.

This report summarizes the findings of the Committee on Biosphere Effects of ELF. The objective was to:

1. assess the adequacy of existing data as a basis for determining biological and ecological effects due to Seafarer;
2. identify the effects, if any, that may be of major concern; and
3. identify critical inadequacies in the available data and to suggest research projects designed to produce needed data.

Some 17 specialists in biology, zoology, medicine, electrical engineering, participated on the committee, and they were supported by some 38 outside consultants. Specifically addressed are the biological impact of Seafarer fields, which are in the order of a few tenths of a Gauss magnetic field, and electric field intensities in the order of 100 V/m or less. Owing to the presence of the time-varying magnetic field, direct earth conduction shock effects on biological systems are also considered. The total number of references cited exceeds 400, but considerable duplications exist because each section's references are kept separate.

In terms of the Committee's findings, all of the published data available were reviewed and considered, including: reports of both negative and positive findings; works which were considered to be conducted on a firm scientific basis; and those which, at best, could be considered only pilot or brief investigations.

Some 14 pages of carefully-worded conclusions and findings are presented, and these should be referred to directly by those who have a major interest in this particular area. However, briefly, the conclusions are as follows: the Committee found no basis for the possibility of any adverse effects associated in the areas of genetics, fertility, growth and development, human serum triglyceride concentrations, circadian rhythms, behavior (with some exceptions), mammalian neurophysiology and behavior, ecology, plants, and some organisms.

The Committee did recommend substantial design changes in the Seafarer antenna system which would minimize a highly-improbable, but yet possible, direct conduction shock via the horizontal electric fields in the ground. They qualify their recommendations to include the continued research in the areas of biophysics, and physiology of magnetic and electric field detection and studies related to the behavior of birds, insects, bacteria, and electrosensitive fish. Further research on the underlying mechanisms of cell division, information processing and integration in complex nervous systems, is also recommended.

Summarizing its position, the Committee made the following statement:

> Recognizing the limit of its charge, the Committee makes no recommendation as to whether the Seafarer antenna should be constructed. It will be up to the citizens and the government of the United States to consider the cost, risks, and benefits, associated with the Seafarer System. The Committee's charge was to identify and evaluate possible biological effects. On the basis of the information available, the Committee concludes that, except for possible electric shock hazards, the likelihood of serious adverse biologic effects of Seafarer is very small. In any case, it is appropriate to recall here that the Navy presentation at the Committee's first meeting (February 11, 1966), included a pledge that, 'if a functioning Seafarer antenna were found to have deleterious effects, its operation would be discontinued.'

The depth and breadth of material covered in these four documents, as well as their critical review of specific experimental evidence, makes them important reading for those concerned with possible biological effects caused by ELF fields.

2.4.5 Research Publications Submitted in Response to Federal Register Notice

As previously noted, a variety of material has been submitted in response to the Federal Register Notice which deals directly with reports on biological interactions due to electromagnetic fields. Table 2.11 presents a summary of the data and material which was submitted. The table provides information on the test subject, investigator, field parameters,

TABLE 2.11

SUMMARY OF BIOLOGICAL EFFECTS SUBMITTALS

Test Subject (Investigator)	Electric Field (V/m)	Frequency (Hz)	Biological Parameter Examined	Results	Reviewed by
Substation workers in U.S.S.R. (Asanova and Rakov, 1966)	$8\text{-}14.5 \times 10^3$	50	various clinical studies	(+) nervous system disorders	Shepard & Eisenbud, NAS
Chick embryos and young birds (Bankoske, et al., 1976)	67×10^3	60	hatchability, activity, growth and behavior	basically (-) one experiment showed initial increase in growth of exposed chicks	NAS
Cats (Bawin, et al., 1973)	(Power density less than 1 mW/cm^2)	a	EEG	(+) positive effect on performance, changes in brain rhythm	NAS, EIS
Survey of Farmers, Effect on plants & animals (Busby, 1974)	$< 10^4$	60	animal grazing habits, milk production, crop yield	(-)	Shepard & Eisenbud, EIS
Subcutaneous cells of rats (Gann and LeFrance, 1974)	to 600×10^3	60	growth and survival	(-) below 200×10^3 V/m (+) cells died at 600×10^3 V/m	NAS
Humans in laboratory (Hauf, R., 1974)	$1\text{-}20 \times 10^3$	50	blood values, blood pressure pulse, ECG, EEG, reaction time	(+) leukocytes, neutrophila, reticulocytes increase but within normal range (-) other factors	Shepard & Eisenbud, EIS (Bridges & NAS review equivalent 1973 paper)
Human (Johansson, et al., 1973)	20×10^3	50	psychological tests	(-)	Bridges, Shepard & Eisenbud, EIS
Human (Johansson, et al., 1972)	20×10^3 at head	b	subjective feeling and psycholotical functioning	(+) a few subjects showed reduced ability and tension for pulse test (-) for sine wave test	
Mice (Knickerbocker, et al., 1966)	160×10^3	60	genetics, growth & development	(+-) slight weight depression of exposed male progety	Bridges, NAS
Human Linemen (Kouwenhoven, 1966)	Fields encountered in normal line and barehand work	60	physical examination CV, thyroid, kidney, urine, ECG, EEG, visual, auditory, X-ray, emotional stress	(-)	Bridges, NAS
Human, lice, yeast, bacteria, wheat germ (Konig, 1962)	1-2	c	human reaction time, growth of other test specimens	(+) reaction time increased or decreased depending on signal characteristics. Growth changes in other specimens	NAS
Rats (Marino, 1974)	15×10^3	50	blood proteins, steroids and weight	(+) weight (decrease), albumin (increase), corticosterone (decrease	NAS, Shepard and Eisenbud
Humans--Comparison of "Operations" to "Maintenance" personnel U.S.S.R. (Sazanova, 1967)	open switchyard environment	50	temperature, pulse, blood pressure, reaction time, flicker frequency, adductor muscle reaction	(+) average blood pressure of maintenance personnel lower	NAS, EIS
Human, Lineman (Singewald, et al., 1973)	Fields encountered in normal line and barehand work	60	same as Kouwenhoven, 1966; this is a follow-up report	(-)	Shepard & Eisenbud,
Humans--Comparison of those near and far from 200-400 kV lines (Strumza, 1970)	$< 7 \times 10^3$	50	visits to and from physicians, use of medicine, medical histories	(-) no statistically significant difference	Bridges, Sheppard & Eisenbud, EIS
Farm animals (Ware, 1974)	$< 10^4$	60	grazing nabits	(-)	Bridges, Shepard & Eisenbud

NOTES: (a) 147×10^6 modulated by ELF signal. (b) Pulse simulating lightning, 3-14 Hz swept sine wave. (c) 2-100. Natural and man-made simulations of geomagnetic signals.

biological parameter examined, result, and an identification of the previously cited major review which provides discussion of the work.

Of the 16 submissions listed in Table 2.11, nine have indicated some form of positive result. That is, the investigator has stated some observable influence due to the applied field. Although negative results must be viewed with equal care as positive results, the following paragraphs will provide a brief discussion on each of the papers or works that have indicated positive results. The discussions that will be presented, will summarize the views presented by the previous reviewers as indicated.

- Asanova and Rakov, 1966

  This is a Russian work indicating various effects on substation workers. Shepard and Eisenbud review this paper in detail, listing the changes in blood values reported as a result of hematological tests on the subjects. They note that the authors do not discuss the implications of the blood findings except to call for more extensive studies of liver function and blood protein fractions. They note that since numerical data are omitted, the statistical or clinical importance of the noted effects are precluded, and because of the lack of a control population, it is not possible to draw conclusions from this report. They conclude that despite the flaws, this study is significant in that it has raised questions of human health effects following prolonged exposure, and further epidemiological studies are indicated. Shepard and Eisenbud also note that although the reports by Kouwenhoven, 1967, and Singewald, 1972, are sometimes cited as a contradictory finding, the daily exposure periods, field intensities, and work duties of the two studies are different.

Bridges does not review the Asanova and Rakov article; however, he does review related later papers by Korobkova, 1972, and Krivova, et al., 1975, and draws the conclusion that factors other than the electric field which may be found in the switchyard are probably of great significance in determining the results reported. He notes that the U.S.S.R. switchyard investigations did not consider the possibility of low frequency or infrasonic acoustical noise or vapor pollutants as being possibly important concomitant factors.

- Bawin, et al., 1973

This paper has been discussed in both the National Academy of Sciences work and the Navy's Environmental Impact Statement. Both reviews note the particularly strong effects that were observed by Bawin, et al. The experiments were conducted at a frequency, 147 MHz, which is in the VHF frequency range, which is well above the ELF frequency range. However, the VHF signal used in the Bawin study was modulated by an ELF signal in the brain wave frequency range. The authors believe that the high frequency radiation acted as a carrier wave for the ELF signal, which was actually detected by the cat's brain. The authors ruled out any thermal-effects and demodulation processes which might occur at the interface between implanted electrodes and tissue. The National Academy of Sciences' review notes that the reported effects only occurred when the ELF modulation was at the same frequency as the intrinsic brain rhythm "signature," and further notes that such major modifications in brain rhythms have not been reported for ELF field exposure.

- Gann and LeFrance, 1974

In this work, Gann and LeFrance examine the effects of 60 Hz fields on the growth and survival of cultures of subcutaneous cells of the rat. They found that there was no noticeable effect due to the exposure on the cultures at a field intensity of 200 kV/m. However, they found that at a field intensity of 600 kV/m, the cells died. In reviewing this work, the National Academy of Sciences made note of the importance of no effects at a field of 200 kV/m. This field is well above the field to be expected in the vicinity of EHV transmission lines. The National Academy of Sciences also notes that with regard to the effects noted at the 600 kV/m field level, this may have been due to factors other than the electric field itself. They note the complications inherent in performing tests at such field levels, and suggest that discontinuities in the test setup could have resulted in enhanced fields and possibly corona. The investigators indicated that secondary effects were excluded from the experiment; however, the NAS notes that no indication was provided on how it was determined that no such secondary effects did indeed occur.

- Hauf, 1974

This research work utilized human test subjects, who were exposed to various levels of electric field intensity up to 20 kV/m for a 3 hr test period. The investigators studied the effects of the field on the reaction time, blood pressure, pulse, ECG, EEG, blood status, thrombocyte, reticulocyte, clotting time, and red cell sedimentation rate. The investigator noted that the leukocytes, neutrophils, and reticulocytes showed a slightly greater increase after the field exposure than in the controls. He further noted that the values remained in the normal range and a direct relation to the field strength could not be shown. However, in reviewing this work, Shepard and Eisenbud note that the manner of data presentation makes it difficult to interpret the author's conclusions and cautiously suggest that the changes noted in these parameters may indicate a substantial field effect. Shepard and Eisenbud further caution that without more information on the data, it would be unwise to take the presentation that they give as conclusive evidence. In a later investigation, a student of Hauf, Rupilius, 1976, performed similar experiments utilizing both electric and magnetic field excitation of the test subjects. Rupilius notes that the slight increase in leukocytes, neutrophils, and reticulocytes described by Hauf could not be observed as significant in the experiments that he performed. Rupilius notes that all values in his experiments were in the physiological range throughout.

- Johansson, et al., 1972

This work was not reviewed by any of the previously noted major review works. In this work, Johansson, et al., studied both the subjective feelings of displeasure and objectively measurable disturbances of the physiological and psychological functions of volunteer human test subjects under two different electric field test conditions. The first test condition was with a voltage impulse field simulating that which commonly appears in connection with violent lightning storms, with a crest gradient on the human head of about 20 kV/m. The second test condition was for a sinusoidal field of approximately 200 V/m, which was swept in frequency from 3 Hz to 15 Hz, with a repetitive sweep time of 70 seconds. The investigators noted that the test condition did not lead to any general reduction of human ability. Yet, a few subjects showed a decrease in ability and reported feelings of tensions and headaches during the impulse field exposure condition. Since the effects which were noted occurred for conditions which simulated natural phenomena such as lightning, there is not a direct relationship of this investigation with the fields that might be anticipated from power lines. In the test that used sinusoidal frequencies, which might be more related to the power line situation, no effects were noted; however, the field levels used were relatively low.

- Knickerbocker, et al., 1966

In this study, mice were exposed to a very high level (160 kV/m) electric field for a long duration (approximately 1500 hours). The effect noted in the experiment was that the male progeny were consistently slightly lower in weight than the young of control males. The National Academy of Sciences, in reviewing this work, notes that due to the high fields that were used, corona was heard when the exposed animals stood up. They further noted that the exposed animals did not drink during the exposure period, because of electric shocks from the water bottle. Therefore, the exposure was terminated for short periods to allow the animals to drink water. The NAS notes that the control animals had water available ad lib. They also noted that the exposed and control progeny were kept in different parts of the room; the exposed group faced a window, with the opportunities to lose more body heat by radiation, while the controls faced a wall. The authors considered the noted weight gain variation as inconclusive and suggested additional research.

- Konig, 1962

In this work, Konig investigated the existence of naturally occurring atmospheric signals in the frequency range of 10 Hz, and investigated the effects of such signals on living organisms. Natural signals at about 9 Hz were identified that have a sine wave characteristic, as well as signals in the 3-5 Hz range that have an irregular wave shape. The natural occurrence of these types of signals were correlated with human reaction time and it was noted that the reaction time improved during periods when the atmospheric signal had the sinusoidal characteristic; and reaction time decreased during periods when the non-sinusoidal lower-frequency atmospheric conditions prevailed. Additional laboratory tests were also reported using simulated signals similar to those he observed in nature, to study the effects on a variety of organisms, including peach leaves, lice, lactic acid, bacteria, yeast, and wheat germ. He notes that all of these experiments have made evident the fact that electrical fields similar to those which have been recorded in nature can cause effects of a medical, zoological, and biological nature.

The National Academy of Sciences has reviewed several of the works reported by this investigator, including this particular work. With regard to this particular work, the NAS notes that Konig in a later publication pointed out that these studies were incomplete and lacked statistical significance. Finally, the major emphasis in this work is for frequencies which are considerably below the power line frequency of 60 Hz.

- Marino, 1974

Marino reports a series of experiments in which rats were exposed to a 60 Hz electric field of 15 kV/m. The investigator reports alterations in serum proteins, corticoids, and body weights, which he indicates are consistent with a reaction to an environmental stressor. Based on these results, the author proposes a tentative safety level for chronic human exposure to 60 Hz electric fields of 150 V/m.

This research has been extensively reviewed by the National Academy of Sciences and Shepard and Eisenbud. The National Academy of Sciences questioned the author's conclusion regarding the reported changes in corticosterone and cortisol, noting that the observed changes were in the opposite direction usually noted in chronically stressed animals, while the author attributed this change to an electric field stressor. The NAS notes differences in the housing of test and control animals for some experiments as well as other procedural problems, and concludes that it is difficult to see any significant cause and effect relationship in these experiments.

In reviewing this work, Shepard and Eisenbud note possible artifacts due to animal housing, cage vibration, microcurrents and microshocks or field distortions caused by the metallic feed trough, but notes that these factors were considered in later experiments by this investigator. Shepard and Eisenbud also note a variety of factors which can give rise to changes in corticosterone plasma levels and conclude that these levels are subject to so many influences that caution is required when interpreting data of this kind. They further note that it is not possible to rule out the possibility of procedural influences contributing to these results.

The Marino studies have been the subject of considerable discussion and testimony at hearings before the State of New York Public Service Commission. These discussions did not result in any agreement being reached by the various parties with regard to the significance of this work, as is evident in the Reply Brief-Common Record Hearings, 1977. Since this work of Marino has not been accepted at face value by reviewers (NAS, Shepard and Eisenbud), and since the work has not been repeated in other laboratories, under ostensibly identical conditions, considerable caution appears warranted in considering the implications of this work.

- Sazanova, 1967

This work appears to be an extension of that reported by Asanova and Rakov, 1966, in which the influence of the environment in 400-500 kV switchyards on maintenance staff were investigated. This work and that of Asanova and Rakov appear to form the basis for the paper by Korobkova, 1972, in which rules were set forth that limit the duration that U.S.S.R. maintenance personnel can remain in various levels of electric field (Table 2-10). The Sazanova study utilized two groups of personnel. The first, which were maintenance personnel, worked in the electric field no less than 5 hr per shift. The second group were operating personnel, who worked in the electric field not more than 2 hr per shift. The investigator reports central nervous sytem changes and physiological changes in the maintenance staff that were not observed in the operating personnel. Based on the investigation, the author concludes that the extent of functional change in the organism is in direct dependence upon the duration of work under conditions of the action of electric fields, that is, changes invoked by the field proceed in a cumulative fashion.

This conclusion was apparently the stimulus for the dose-related work rules as noted in Korobkova.

As noted in the discussion of the Asanova and Rakov paper, the Russian works have been criticized. The National Academy of Sciences states that these works do not provide adequate field measurement and exposure data. The NAS further notes that the heart rate differences at the end of the day for the two groups appear to be due to increases in rate for the operating personnel, rather than to the maintenance personnel, whose rates were essentially unchanged. They also note that the average blood pressure of the maintenance personnel, while being lower than that of the operating personnel, may have been due to differing physical conditions of the two groups or other factors. They also note that the Sazanova work did not indicate that 1) the two groups were similar in age, sex, physical condition, and other pertinent characteristics; and 2) that the work environment for the two groups was similar in all respects except for the presence or absence of the electric field.

Thus, the NAS does not accept this work on the basis that it does not meet the criterion for a well-controlled epidemiological study. That is, the control group should be comparable with the exposed group in all relevant characteristics, except for the exposure itself. They place the burden of demonstrating that a study has met these requirements on the report of the investigation. The NAS report concludes that because the symptoms that have been noted are also caused by many other occupational and physiological factors, it is not possible to establish a cause/effect relationship.

Bridges, 1975, in reviewing colateral factors such as the acoustical environment, points out that the effects observed by the Soviets were for workers within switchyards near transformers. He further notes that experiments with high level acoustical noise, in the 10-100 Hz frequency range, result in responses including headaches, coughing, visual blurring, and fatigue, which are similar to the symptoms attributed by the Soviets to electric field effects on switchyard workers. He notes that magnetostriction within substation transformers creates acoustical infrasonic energy, and questions the conclusions reached by the Soviet workers, since they provided no indication of the acoustical level which existed in the switchyard environment of the maintenance workers.

It can be seen from the discussions of the above biological investigations, that various reviewers have not accepted the investigators' stated conclusions at face value. It is possible that the reviewers' conclusions are not, in all cases, correct either, since they are often working on the basis of poorly written research papers or reports that inadequately describe all relevant aspects of the experiment. The common consensus of these reviewers appears to be that the burden of proof is on the investigator in the reporting of his findings. Since such a large variety of factors can influence the outcome of an experiment, the major reviewers appear to take the stand that the investigator must not only present his results, but must provide adequate information to insure that the noted effect is indeed the result of the cited stimulus.

2.4.6 State of New York Public Service Commission--Common Record Hearings

On 24 November 1974, the examiners for the State of New York Public Service Commission ruled that two active cases, applying for a Certificate of Environmental Compatibility and Public Need to construct transmission lines, be merged for the purpose of investigating health and safety questions on a common record. The two cases were PSC No. 26529--Power Authority of the State of New York, and PSC No. 26559--Rochester Gas and Electric Corporation and Niagara Mohawk Power Corporation.

The Common Hearings on Health and Safety for these two cases extended to July 1977. The specific issues addressed in these hearings were audible noise, ozone, induced electric current shocks, and electromagnetic and electrostatic field effects. The transcript of these hearings continues for almost 14,000 pages.

The Commission has issued an order allowing construction of the PASNY line, but reserved the option of allowing appropriate and necessary modifications or to impose reasonable restrictions on the operation of the line.

In response to the EPA Federal Register Notice, the transcripts of direct testimony of several expert witnesses were submitted. In addition, since the Federal Register Notice submittals, parties in the Hearings have prepared initial Briefs and Reply Briefs at the close of the Hearings.

The portions of the Hearings and subsequent Briefs dealing with the biological effects of extremely-low-frequency fields are relevant to this section of this report. However, due to the extent of the material presented at the New York Hearings, it appears inappropriate for this document to attempt any form of detailed discussion of the issues addressed, points raised, evidence presented, or the arguments and counter-arguments. Instead, in the next few paragraphs, a very brief overview of the conflicting positions is presented. The discussion that will be presented is principally based on the Initial Briefs--Common Record Hearings: Nixon, Hargrave, Devans and Doyle, 1977; Simpson, 1977; Patrick and Feirstein, 1977; and the Reply Briefs--Common Record Hearings: Terry, 1977; Bennett, 1977; Simpson, 1977; Sassone, 1977; Marino, 1977. Specific citations of these Briefs will not be made in the discussion.

The viewpoint presented in the Hearings by the Applicants holds that only evidence which is relevant to the situation under consideration needs to be considered. This relevancy limits the frequencies of concern to the near region of 60 Hz, thus excluding "non-relevant" interactions at, for example, microwave or RF frequencies. A second aspect of relevancy is with regard to the field conditions. The Applicants' viewpoint is that only experimental evidence that is in the range of field levels to be anticipated from the transmission lines ($B \leq 0.5$ gauss, $E \leq 10$ kV/m) is relevant.

The applicants also hold that there are only two known mechanisms in which electromagnetic fields can induce effects or cause harm. These two mechanisms are Joule heating and cell excitation by neuron firing. They contend that these two mechanisms are very well understood and can be analytically modeled, and that beyond this there can only be speculation.

With regard to heating, it is contended that simple calculations show that even in very large 60 Hz fields, gross heating effects are negligible for humans, since the induced thermal flux is negligible compared to the background biological thermal flux; thus, the body temperature rise will be negligible.

With regard to cell excitation and neuron firing, estimates of the required electric field thresholds may be obtained from a variety of sources: nerve clamp experiments, exposures of fish with special current channeling and detecting organs, measurements on artificial simulations and indirect measurements on exposed organisms. The Applicants note that the results of analyzing data from these sources support the notion that a significant threshold for single neuron firing exists at a current density level of about 0.1 mA/cm^2. Routine calculation shows that the induced current density levels produced in humans by 765 kV transmission line E field exposure will be significantly less than this level. Since the Applicants' viewpoint holds that below the threshold for a single neuron firing there can be no neurological effect, it follows that these fields are not a biological threat.

The point of view presented by witnesses for Staff, holds that beyond the two effect categories of the Applicants' viewpoint, there exist other effects that are usually characterized by lower thresholds of current density or E field, but which appear only after long (chronic) exposure of subjects. They argue that experimental models founded on single neuron threshold firing levels do not apply to the lower thresholds for at least two reasons: nerve levels (states) are more complicated than merely fire/no-fire levels--and an organism is a network of neurons wherein the behavior of the network to E field stresses differs from that of a single neuron. They also seem to argue that effects need not even be mediated via neuron firing. In support of this position, witness Henshaw submitted that

> A subthreshold electrical stimulus unquestionably can alter the sensitivity of a cell to subsequent stimuli--it is generally recognized that an electric stimulus insufficient to cause an action potential nonetheless can cause a change in the resting potential of the nerve, causing an altered sensitivity to subsequent stimuli.

The Staff witnesses argue that the Applicants cannot dismiss the roughly 60 experiments cited in support of the position that the electric and magnetic fields of the proposed transmission line will probably cause biological effects in people chronically exposed to them. They note that the evidence must be acceptable since it represents the work of diverse research teams and because many of the reports have been published in prestigious referenced scientific journals. They contend that since the effects have been observed, they cannot be presumed to be safe, when the mechanism triggering the biological response is unknown. And further, exposing people to the fields from the line without informing them of the potential hazard is similar to human experimentation.

The Applicants dismissed the cited experimental evidence by: citing similar null experiments; dismissing many as not meeting the relevancy criteria; noting faulty experimental protocol or interpretation; noting conflicts or inconsistencies in the reported results; pointing out that some of the observed effects were within the normal range of biological variability; and noting that virtually none have been independently substantiated in other laboratories.

In response to the charge that the experiments that they cite are inconsistent, the Staff witnesses argued that the apparent inconsistencies are merely the result of preconceptions of how effects should depend on exposure. Higher field levels need not always lead to larger effects. Experiments cannot all be directly compared, because all the relevant variables have not been replicated. That is, in the absence of a theoretical model that would relate dose to effect, there is no mechanism to reliably predict the effects of dose; and even though the data may appear to violate intuition, this is not a serious concern.

In reviewing the material from the New York Hearings concerning biological interactions of ELF electromagnetic fields, the polarization of the two viewpoints is evident. Both sides have a firm conviction in their own viewpoint and a rigid unacceptance of the evidence presented by the "other side." The unacceptance extends to severe criticisms of the credibility of various witnesses with opposing views.

The Commission has concluded that "the facilities will have the minimum adverse environmental impact, considering the state of available technology and the nature and economics of all the variable alternatives." However, judgments may still be made that could have significant economical impact--for example, with regard to the width of right-of-way; the closeness of dwellings; or other restrictions of the use of the property.

The manner in which reported research findings were critically appraised at the Hearings, strengthens the need for researchers to heed the guidelines set-forth in the National Academy of Sciences document with regard to the conduct and reporting of such research. Very few would question the need for additional research. However, if the research, when completed, is not accepted by major segments of the knowledgeable scientific community, it does little service.

3. ELECTRIC DISCHARGE PHENOMENA

The formation of corona on transmission line conductors gives rise to several side effects which have caused various degrees of concern and have been investigated analytically, in the laboratory and in the field. The three side-effects which accompany the production of corona are the generation of gaseous effluents, principally ozone, the generation of audible noise and the generation of radio frequency noise. These three aspects of corona will be discussed in following sections.

3.1 Discharge Mechanisms

The elemental aspects of corona related discharge are described in the following paragraphs. Corona arises due to the actions of electrons, air atoms and ions under the influence of strong electric fields. Electrons and air ions are either attracted by or repelled from the line conductors depending on the polarity of the conductor charge.

When the conductor is negative, free electrons move away from it. If the electric field at the conductor surface is sufficiently intense, the electrons gain enough energy to form positive ions and release additional electrons due to collisions with neutral air atoms. The collision of electrons with atoms is a multiplicative process, with two electrons resulting from each collision. Further away from the conductor, the free electrons, after losing energy, may combine with neutral atoms, thus producing negative ions.

When the conductor is positive, the electrons are drawn toward the conductor and absorbed by it. Since the electrons are highly mobile in relation to the ions, a cloud of positive ions is left behind. The CIGRE Working Group 36.01, 1974, notes that the positive ions thus formed result in a positively charged protrusion from the conductor, which leads to the formation of a new avalanche ahead of the preceding one. They note

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that this process of ionization propagates away from the conductor much further than the avalanches of negative polarity. The positive avalanche is called a streamer.

The ion production process is not constant, since the ions modify the local field about the conductor. Thus, when sufficient ions are produced in the near vicinity of the conductor, the field is reduced to the point where the electrons no longer gain enough energy for the multiplication process. After a short period of time, the field sweeps away the ions and the process can begin again.

The self limiting nature of the process results in the electron current flow from the conductor occurring in bursts or pulses. The pulses of current flow can be quite short, e.g., with duration in the tens of nanosecond range. The pulse current and pulse repetition rate are a function of the local field intensity.

Since the collision and ionization process changes as a function of conductor polarity and the local field intensity, different distinct modes of corona can be produced. Several different modes may occur at different times during a single cycle of the 60 Hz voltage on the conductor.

The current flow from the conductor during corona production represents a loss of power to the transmission system. The high frequency pulse-like nature of the avalanche current flow gives rise to electromagnetic fields which can couple to nearby communications receiving antennas, being evidenced as noise in the receiver output. The moving corona-produced air ions also cause varying air pressure in the vicinity of the conductor, which can be audibly heard as noise, and causes conductor vibration.

For practically designed EHV transmission lines, corona is principally a foul weather phenomenon. Corona that is produced during fair weather, for aged conductors is largely caused by airborne particles such as dust or bird droppings. When such particles are on the line they cause locally high voltage gradients and thus local points of corona. The surface state of the conductor influences the manner in which water drops adhere or distribute on the line, thus influencing foul weather corona performance.

In the design of an EHV transmission line, many compromises must be made with regard to the corona side effects. While the loss of power which occurs due to corona is of importance to the power industry, the Transmission Line Reference Book, 345 kV and Above notes that as line voltages are increased corona loss considerations become secondary to the audible and radio noise produced by the corona.

Considerable research has been conducted into the various side effects of transmission line electrical discharge phenomenon. Those side effects of most importance to the public are the subjects of the following three sections.

3.2 Ozone Production by Transmission Lines

3.2.1 Introduction

3.2.1.1 Sources of Ozone and Related Oxidants

There are at least three categories of ozone formation which are of interest: (1) photochemical formation in the stratosphere; (2) photochemical production near the earth; and (3) ozone generation associated with electrical discharges.

Ozone is formed in the upper atmosphere when solar ultraviolet light causes the disassociation of the oxygen molecules. Originally, it was believed that such a process does not contribute substantially to the ozone concentrations found near the ground; however, more recent data indicates that this may not be true; see Coffey and Stansik, 1974, 1975.

Significant amounts of ozone are believed to be formed near the ground by the action of ultraviolet radiation with the gaseous emissions of combustion processes, such as automobile exhaust gases, Scherer, et al., 1973. Stansik and Coffey, 1974, suggest that contributions may also arise from hydrocarbons emitted from natural sources. In this process, the ozone concentrations tend to be much greater during periods of intense sunlight that are coincident with meteorological conditions which allow accumulation of industrial and automotive industrial waste gases, such as during an inversion.

It has been known for many years that electrical arcs and corona discharges from electrical apparatus can create ozone and, to a minor extent, other gases such as oxides of nitrogen. The process is quite complex and is generally rather inefficient in terms of total energy required during actual process versus theoretical limit.

Production of nitrogen oxides is more difficult electrically in the corona discharge, since higher electron energies are required. Thus, the yield of NO_x is substantially less than the yield of ozone.

Since ozone is one of the most reactive compounds known, its concentration will continually decrease unless additional ozone is generated or transported to the area. The presence of oxides of nitrogen, some spray can propellants, carbon tetrachloride and other sources of chlorine and bromine can accelerate the recombination of ozone both near and well above the earth's surface. Near the earth's surface, vegetation and other material can act to reduce the concentration.

Thus, the ozone concentration in any given area is a delicate balance between the ozone formed or transported and the destruction of ozone in that area. The decay rate of ozone, and the factors which affect the rate, are of interest in predicting ozone buildups near the transmission lines.

3.2.1.2 Natural Distribution and Concentration

Ozone has been recognized as a significant air pollutant in urban areas, but it has not been until recently that good comparative measurements over wide areas have been developed over a year's time. Recent papers by Stasiuk and Coffey, 1974, 1975, discuss measurements in both urban and rural sites. These show a daily variation of the ozone concentrations in the urban areas which, surprisingly, do not occur in the rural areas. The diurnal variations in the metropolitan areas suggest the presence of some element which accelerates the recombination process during nighttime. Typical ozone concentrations measured on rural mountain top locations during the late summer months range from 30 ppb (parts per billion) to 102 ppb. In the urban areas, the maximum hourly average ozone concentration ranged from 30 ppb to 124 ppb. Note that the maximum values in both the rural (in this case, two mountain tops) and urban areas exceeded the air quality standard of 80 ppb as stated in the National Primary and Secondary Ambient Air Quality Standards for Photochemical Oxidants. It is suggested that the higher rural ozone levels are not primarily due to the transport of ozone and ozone precursors from other urban areas, but could be due to naturally occurring phenomena, such as photochemical generation from non-man-made precursors or the transport of ozone from the stratosphere to the troposphere.

3.2.1.3 Historical Aspects

It has been known for a long time that ozone is generated from electrical corona and arc discharges. This property has been utilized for commercial ozone generators and ozonizers. The fact that transmission lines might generate ozone was considered in 1956 for the first time in conjunction with radio and TV interference tests on transmission lines in a publication by Newell and Warburton, 1956. Liao, Keen and Powell, 1957, investigated corona and radio influence phenomena of thin wires in cylindrical cages and noted that ozone had to be removed by the continuous introduction of fresh air.

In the design of the early EHV lines, the ozone generation was not considered to be a major problem. While ozone is usually noticeable by smell in high-voltage laboratories during repetitive testing, it was not noticed near some of the early high voltage lines and stations. A typical person can detect the smell of ozone in concentrations as low as 20 to 50 ppb until he becomes acclimated. This provided fairly good evidence that the overhead transmission lines would not create environmental ozone problem. This conclusion was supported by simple analyses during the preliminary design for some early EHV transmission lines.

Unfortunately, various episodes associated with air pollution in general occurred in 1948 at Donora, Pennsylvania, and in 1952 in London. Although the problems were air pollution from sources clearly not associated with power lines, these episodes and others have created an acute awareness of the air pollution problems. Consequently, the question of generation of any pollutant, and ozone in particular, by EHV transmission lines, has been raised as a part of this general environmental issue. Foremost in the raising of public concern over these issues were the allegations presented in Young, 1973, that significant ozone at ground level might be expected from EHV transmission lines.

In order to resolve this problem, the American Electric Power Service Corporation sponsored an extensive program of research in 1970 and 1971 to determine if gaseous products from 765 kV transmission lines could cause environmental problems. Other power companies, such as Commonwealth Edison, initiated field studies in about this same time frame. The U.S. Environmental Protection Agency also sponsored laboratory and analytical studies in this time period.

Past studies have approached the development of the concentration of ozone near transmission lines in a sequential manner involving laboratory studies and analyses, which are then confirmed by means of field measurements. The corona losses associated with transmission lines are determined and then the efficiency with which ozone and other oxide gases are generated is determined. Once the amount of gas near the conductor is determined in terms of the conductor geometry and operating voltages, the atmospheric diffusion characteristics and ozone decay properties are investigated to determine the possible ground-level concentrations. Hopefully, the final result would be confirmed by a series of field tests. Following the sequence of this scheme, the work is reviewed in terms of three major areas:

1. laboratory measurements;
2. prediction; and
3. field measurements.

3.2.2 Laboratory Measurements

Laboratory measurements of the production of ozone as a function of corona loss, expressed in terms of the conductor voltage gradient, conductor geometries, operating voltages, and meteorological parameters have been reported in a series of six papers. The most comprehensive study was that reported by Scherer, Ware and Shih, 1973. This paper reported the results of a comprehensive program involving laboratory prediction and field measurements. The laboratory work was conducted by Ion Physics Corporation, American Electric Power at Canton, Ohio and Westinghouse Electric Corporation. Preliminary results of a detailed laboratory study are reported by Sebo, et al., 1972, on a program conducted for American Electric Power by the staff at Ohio State. Roach, et al., 1974, summarizes extensive laboratory and analytical work conducted by Westinghouse. Frydman and Shih, 1974, report additional studies on the effects of the environment on ozone production which are based on tests conducted at American Electric Power Service Corporation's Canton laboratory. The more recent paper by Sebo, et al., 1975, provides a comprehensive summary of the laboratory work conducted at Ohio State University on ozone production rates for a variety of conductor geometries and weather conditions. Whitmore and Durfee, 1973, investigated wind and humidity effects on a program sponsored by the EPA, and presented results comparable to those reported by Scherer.

The above laboratory studies established the ozone production rate as a function of conductor geometry, operating voltages and simulated weather conditions. The following general conclusions were noted.

1. The ozone production rate W (usually expressed in grams O_3 per killowatt hour of corona loss, or pounds of O_3 per killowatt hour) is a function of temperature and humidity, following the relationship

$$W = A\exp\left[-\left(\frac{T}{B} + \frac{H}{C}\right)\right]$$

where

T is the temperature

H is the humidity

A and B depend on conductor diameter

C is a constant.

Thus, the ozone production rate decreases with increasing temperature and humidity.

2. For otherwise identical situations, the production rate decreases with an increase in conductor diameter.

3. The ozone production rate increases during rain. Rain causes the appearance of positive corona streamers, and positive streamers result in greater ozone production rate (W). Heavy rain causes a higher ozone production rate than does light rain.

4. The ozone production rate is affected by the air flow rate, with the production rate decreasing as the air flow rate increases, at least for smaller conductors.

5. For dry conductors the ozone production rate increases very rapidly with the conductor surface voltage gradient and corona loss when positive corona streamers are first formed. However, for further increases in the voltage gradient at the conductor surface, the ozone production rate tends to become nearly a constant.

6. The ozone production rate for rain conditions does not appear to be a strong function of either the conductor surface voltage gradient or the corona power loss.

7. The average ozone production rate over many conditions is (1/235) lb/kWh.

8. The half-life of ozone was observed, on one experiment, to be approximately 10 minutes. Under more carefully controlled conditions, the half-life was 45 minutes and, under conditions of a water spray, was 27 minutes.
9. Once ozone is formed, it has a tendency to diffuse upward, possibly from convection currents introduced by local conductor heating.
10. The nitrogen oxide production rate is roughly 1/10th that for ozone.

3.2.3 Analytical Prediction

Based on laboratory measurements, the analytical prediction of ozone concentrations near high voltage transmission lines has been considered in papers and reports by Scherer, *et al*., 1973; by Roach, *et al*., 1974; by Whitmore, *et al*., 1973; and by Snow, *et al*., 1976.

Essentially, the experimentally determined ozone production rates over an incremental section of the overhead conductors is used in diffusion studies to determine how the ozone diffuses or propagates to regions near the ground. Air diffusion models which have been developed over the last half century are used. However, to use these models for ozone diffusion from extended transmission lines, some unrealistic assumptions must be made, such as a very low velocity wind prevailing in one fixed and arbitrary direction over very long periods of time during inclement weather. In addition, the recombination rate of the ozone is also important, particularly during precipitation, but is not known. The earlier calculations did not consider decay rates, which tend to reduce ground level ozone concentrations; thus, the predictions resulted in unrealistically high ozone levels.

Two limiting cases are considered, that is, where the wind is perpendicular to the transmission line, and where the wind blows parallel to the transmission lines. It is evident that in the latter case, for very low non-turbulent wind conditions blowing parallel to the transmission line, a progressive accumulation along the line might occur under certain idealized and hypothetical conditions. Even under idealized conditions, certain data necessary for a precise calculation is missing, such as the recombination time of ozone under conditions of precipitation. Further, the hypothetical case in which the wind blows in a constant direction with an invariant very low velocity parallel to the line under conditions of heavy precipitation seldom, if ever, occurs. (The ozone generation at the conductor is maximum during heavy rain.) The actual variations of these meteorological parameters must be considered before a realistic assessment or calculation can be made.

A sample calculation for ozone concentrations, based on hypothetical weather conditions, is presented in Scherer, *et al*, 1973. The calculation is based on an assumed corona loss level and production efficiency of the effluents, incorporated with the EHV transmission line configurations. The key parameters are:

Operating Voltage:	765 kV rms line-line
Line Height:	75 feet average (22.86 m)
Total Line Length:	• Infinite for transverse wind • 2.5 miles (4 km) for longitudinal wind
Production rate of Total Oxidant:	0.08 oz/kWh* (2.27 g/kWh)
Foul-weather corona loss:	(1) 79 kW/mi-3 phase (49 kW/km-3 phase) (2) 135 kW/mi-3 phase (83.7 kW/km-3 phase)

The results of the maximum ground level concentrations of the total oxidants are summarized as follows:

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*ounce or gram per kilowatt-hour

Table 3.1

CALCULATED MAXIMUM GROUND-LEVEL OZONE CONCENTRATIONS

Transverse Wind Speed (mph)	Maximum Concentration (ppb)	
	(1)*	(2)*
1	0.7	1.2
2	0.3	0.6
4	0.2	0.3
10	0.1	0.1

Longitudinal Wind Speed (mph)	Maximum Concentration (ppb)	
	(1)	(2)
1	11.3	19.3
2	5.7	9.7
4	2.8	4.9
10	1.1	1.9

*Columns (1) and (2) represent the two different foul-weather corona loss conditions described in the text.

The authors state that the maximum concentrations for the longitudinal wind case should probably be reduced by a factor of 4, since the diffusion calculations for the parallel wind conditions are sensitive to the length of the line (or the constancy of direction of the wind). The reduction of ozone concentration due to recombination was not included in this analysis.

Whitmore, et al., 1973, has made rough analytical estimates of the ozone contributed by power lines, and reports that transmission lines appear to contribute only minimally to local ozone levels in areas where transmission lines exist.

The plume dispersion theory and lab development of ozone production rates have been used for most estimates of the ozone concentrations near transmission lines. The more accurate estimates are for the wind perpendicular to the transmission line. Unfortunately, the most important case is the one in which ozone can be progressively concentrated by a wind blowing parallel to the transmission line. In this instance, the inaccuracies embedded in assumptions are cumulative as well, and generally tend to increase calculated values. As a consequence, parallel wind calculations made to date may be regarded as plausible upper bounds subject to downward revision.

In evaluating the environmental considerations for two proposed 765 kV lines for the Detroit Edison Company, Shah, 1973, plots the anticipated ozone concentration profile for the two proposed lines under the "worst possible weather conditions." His predictions are shown as Figure 3.1, which has been extracted from the cited report.

The calculations made with the plume dispersion model also have another potentially serious limitation. The usual dispersion model, which includes eddy diffusion due to the wind, contains a factor, Q/v, where Q is the ozone generation

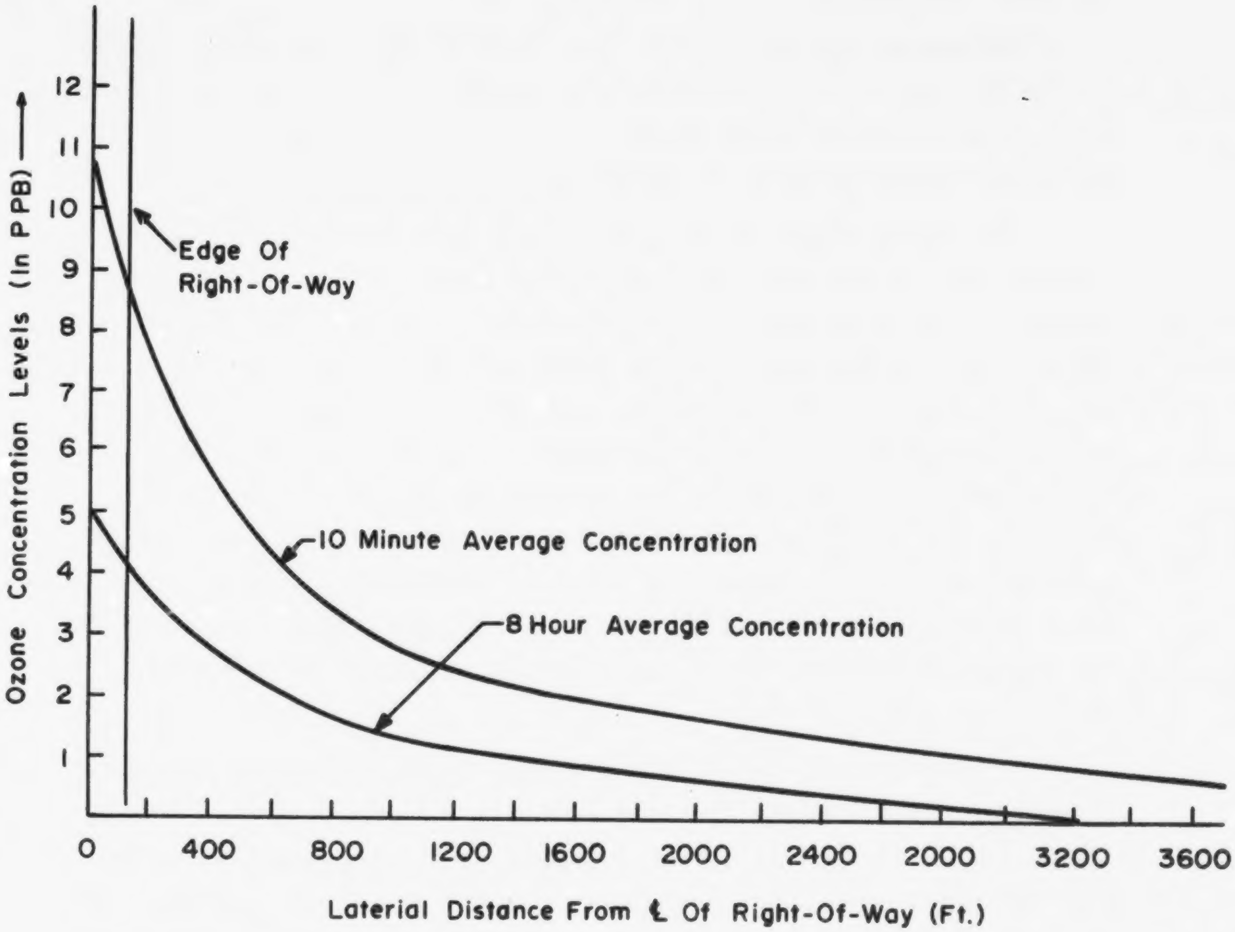

Fig. 3.1 LATERIAL OZONE CONCENTRATION LEVELS OF TWO 765kV DECO LINES (FROM SHAH, 1973)

rate in grams per second or pounds per second, and v is the wind velocity. If v is made arbitrarily small, then one can calculate very large values of Q/v, and hence large concentrations of ozone. However, the model is not valid for very small v.

One reason for the invalidity is that these models do not take into account the ozone recombination. Another reason is that for very low values of v the air flow will be laminar, and there will be no eddies. Snow, Shiau and Bridges, 1976, have theoretically investigated the ozone concentrations near transmission lines for the zero wind condition by using molecular diffusion theory. The results of this analysis show that significant amounts of ozone concentrations are not likely at ground level, even assuming periods of absolutely still air for as long as 54 hours. Figure 3.2 shows a theoretical curve extracted from Snow, et al., 1976.

This curve is based on calculations for a single wire that assumes:

- the ozone production rate is constant at 1/279 lb/kWh (this is slightly less than the average value of 1/235 lb/kWh given in Sebo, et al., 1975);
- the corona loss is 30 kW/mile;
- the ozone is dispersed away from the transmission line into the air with a diffusion constant of $D = 0.13\ cm^2/second$;
- the ozone recombination rate half-life is 27 minutes.

The curve of Figure 3.2 shows negligible concentrations of ozone and the limiting effect caused by ozone recombination.

The corona loss value used in these predictions are approximately a factor of 5 less than the value of 84 kW/km for three phase 765 kV transmission lines under foul weather conditions, as given by Sebo, 1975. Increasing the values shown

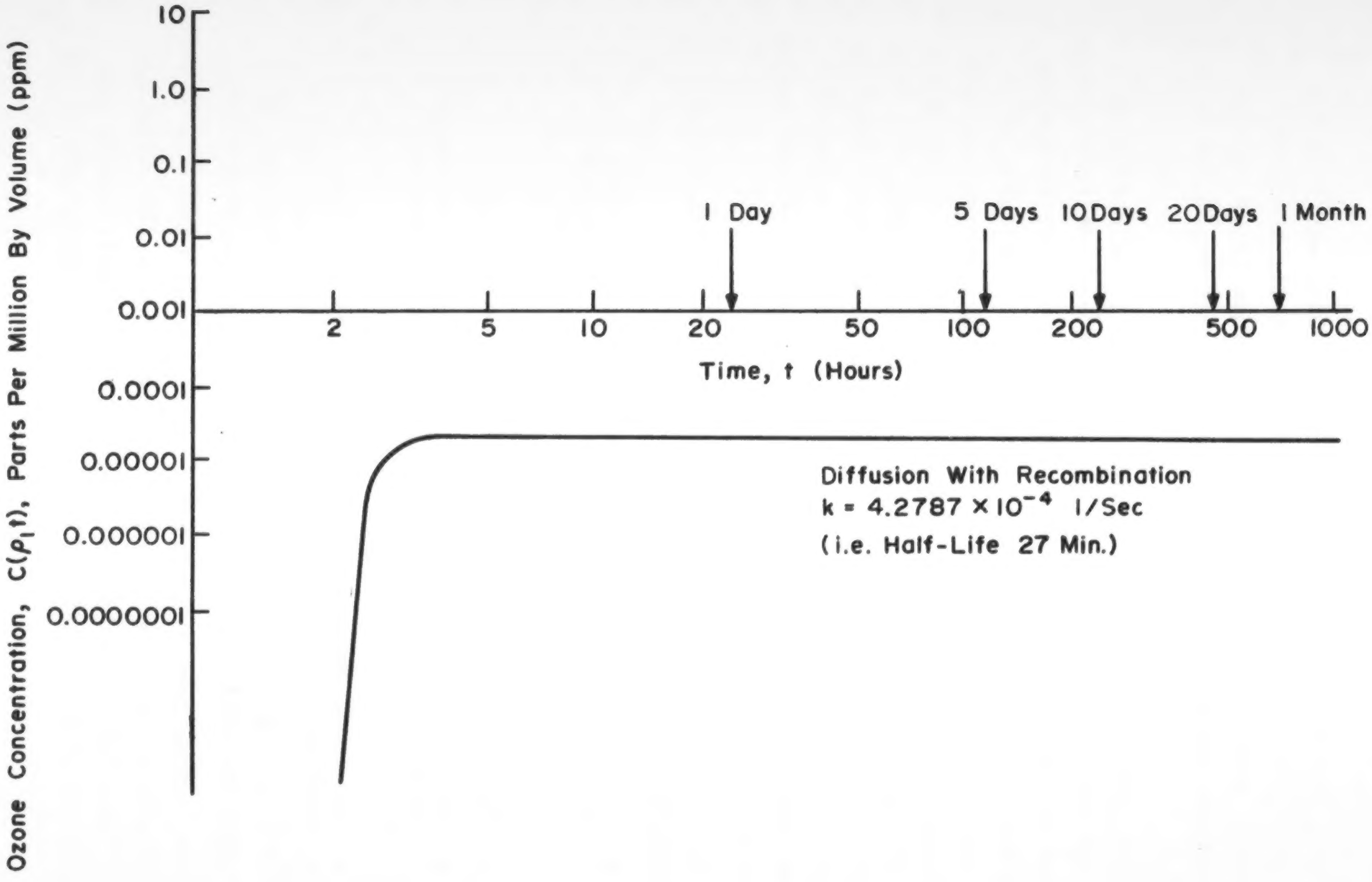

Fig. 3.2 OZONE CONCENTRATION AT DISTANCES 62 FEET AWAY FROM SINGLE WIRE TRANSMISSION LINE (FROM SNOW, et al 1975)

in Figure 3.2 to account for this difference in assumed corona loss should not affect the basic conclusion that the ozone concentration under the no-wind condition should be no more than a few parts per billion.

3.2.4 Field Measurements

Results of six measurement programs concerning the field measurement of ozone from overhead EHV lines are summarized in Table 3.2. In general, all measurements were capable of resolving concentrations on the order of 2 ppb to 5 ppb out of an ambient which generally ranged from 20 to 60 ppb. Also note that these represent the measurements of five separate groups, three of which were not connected with or sponsored by the power industry. Some of the measurements were conducted over at least a two year period of time at fixed locations, whereas others were conducted in a variety of locations over shorter intervals. A typical procedure is to determine the ambient levels by locating measurement sites well away from or upwind of the power line, and then comparing these results for locations near to or downwind from the line. The conclusions of all of these studies were that the power line provided no significant addition to the ozone concentration in the area. During one preliminary study, only one measurement indicated a higher ozone concentration and this could not be repeated.

In responding to the Federal Register Notice, Young, 1975, noted that many reported ozone field tests were conducted while the lines were operated 8 to 10% below the rated voltage. The results on ozone generation by Sebo, 1975, indicate that the ozone production rate is rather independent of both the conductor gradient and the corona loss under foul weather conditions. Under fair weather conditions, the normal design voltage of the line should not produce significant positive streamers. Thus, by the considerations presented

Table 3.2

SUMMARY OF PUBLISHED OZONE MEASUREMENTS MADE NEAR EHV LINES

Investigator/ Sponsor (Citation)	Line Voltage	Measurement Period	Measurement Locations	Conclusions
Research Triangle Institute/ Environmental Protection Agency (Decker and Strong, 1971)	230 kV	March 1971	Upwind, downwind, beneath line, at ground level	Power line had no significant effect on ozone concentration in area
Research Triangle Institute/ Environmental Protection Agency (Research Triangle Institute, 1973)	500 kV	Aug-Sept 1972	5 ground level locations, upwind, downwind, beneath line	No significant variation introduced by line
American Electric Power and Battelle/American Electric Power (Frydman, *et al.*, 1973)	765 kV	10/18/70 to 10/21/71, but shorter intervals at any given location	20 locations	No ozone formation attributed to power line for variety of terrain and weather
IITRI/Commonwealth Edison (Fern, *et al.*, 1974)	138 kV, 345 kV and 765 kV	4/1/71 to 11/15/72, periods of 6 months to 1 year	4 locations, urban and rural	High voltage transmission lines up to 765 kV do not generate measurable ozone above ambient under any weather condition
Ohio State University/ American Electric Power (Heibel, *et al.*, 1972)	765 kV	7 month continuous in one location before and after line energization	Up and downwind in one general area	No measurable quantity of ozone within 2 ppb could be detected due to EHV line, either short or long term
Oak Ridge National Laboratory (Auerbach, *et al.*, 1973)	500 kV	4/6/72 to 5/16/72	Approx. dozen locations near and distant	No increase in ozone concentration near line with one exception which was not repeatable

in Sebo, 1975, the ozone production should be rather insensitive to small changes in surface gradient.

3.2.5 Measurement Methods

Until about 1970, ozone monitoring instruments depended on the reaction of ozone with an aqueous potassium iodide solution. The potassium iodide solution would also react with other oxidants to record a total oxidant concentration. Certain other gases, i.e., sulfur dioxide, could negatively affect the indicated ozone concentration. Within the past five years, other instruments have been developed which measure ozone in terms of certain of its unique properties. Two gases, nitrogen oxide (NO) and ethylene (C_2H_4) react with ozone to emit light in proportion to the amount of ozone reacting. This chemiluminescence principle is the basis for a number of instruments currently being manufactured. Ozone absorbs a specific band of ultraviolet light. This characteristic has been developed into another technique for measuring ozone in a 1 or 2 ppb range.

Currently, there are at least ten manufacturers constructing ozone monitoring equipment based on the above principles. Each particular instrument will have certain advantages and disadvantages. None can be considered perfect. All are subject to interference by other gases or particulate matter to some degree. Suggested maintenance and servicing vary with the instruments, sensing components, and the sampling system. Accuracies of $\pm$ 2 ppb are claimed by the manufacturers, but only under ideal conditions such as might be obtained in the laboratory. Field experience has shown that instrument "A" does not always read the same as instrument "B"; it might read higher or lower depending on atmospheric conditions. Studies have been made to provide "correction factors" for certain instruments compared to the so-called prime standard. Yet these correction factors may not always be applicable to field measurements made at low ozone levels (10-80 ppb), because the instruments themselves can vary up to 8 ppb, when sampling a constant ozone supply.

3.2.6 Conclusions

There are two major biological reasons why ozone is of concern: (1) the destruction of ozone in the stratosphere with the possible health consequences associated with increased ultraviolet light (such as skin cancer) near the earth's surface, and (2) the biological effects of abnormal concentration of ozone near the earth's surface. Only the latter is of interest in discussing power line effects. The effects of ozone and similar oxidants on humans, animals and vegetation has been presented in detail by the U.S. Department of Health, Education and Welfare, 1970. This forms the basis for the National Primary Air Quality Standard for photochemical oxidants of an 80 ppb maximum one-hour arithmetic mean concentration not to be exceeded once a year.

The ozone values predicted by both Scherer, et al., 1973, and Roach, et al., 1974, based on laboratory measurements and diffusion analyses, are in the order of 1 ppb or less for the transverse wind. Since the best measurement accuracy for conducted field tests was in the order of 2 ppb, the more accurate theoretical predictions and measurements results to date are self-consistent. Predictions by Snow, et al., 1976, for the zero-wind condition indicate that problems should not be encountered for this special case, even for abnormally long periods of calm.

The view that ozone problems are not likely to occur from EHV transmission lines is supported in testimony in behalf of the New York State Attorney General at the New York State Public Service Commission Hearings by Leone, 1975, and Carroll, 1976. Leone addresses the ozone effects on vegetation and concludes that for the maximum predicted concentrations from 765 kV transmission lines, no appreciable effect on New York State vegetation should be expected. Carroll testifies concerning the effect of ozone on animals and man. He concludes that animals which have been tested show effects similar to those described for humans, and that he does not believe that the estimated ozone concentrations from transmission lines will have any demonstrable effect on human health.

In the initial Brief by Staff, at the termination of the Common Record Hearings on Health and Safety of 765 kV Transmission Lines before the State of New York Public Service Commission, Simpson, 1977, provides a summary of the ozone related testimony. He notes that no significant adverse impact was predicted by any witness in the hearings. Simpson concludes that--"while such"--ozone related-"research may prove interesting, Staff believes that the priority for it must be regarded as low."

3.3 Audible Noise

3.3.1 Introduction

Audible noise (often indicated as AN) is considered to be the limiting design parameter for the design of transmission lines for voltages of 500 kV or over, as noted in the Transmission Line Reference Book, 345 kV and Above, 1975. The electric power companies and appropriate groups of the IEEE have recognized the problem and have sponsored and performed considerable work in this area. Measurement and analysis of transmission line acoustic noise has been a part of several major programs, such as General Electric's Project UHV sponsored by EPRI; Westinghouse's Apple Grove Project, partially sponsored by American Electric Power Corp. (AEP); and Bonneville Power Administration (BPA) The Dalles Project (EHVDC) also sponsored by EPRI. Other measurements and analyses have been conducted on behalf of various parties to the New York State Public Service Commission Hearing concerning a proposed EHVAC line. The Institute de Recherce de l'Hydro Québec (IREG) has also been active in this area. University studies exclusively concerned with acoustical noise have been funded at Oregon State University by BPA and at Massachusetts Institute of Technology, by AEP. More recently, studies of the human response to transmission line noise have been initiated at the National Bureau of Standards by the Energy Research and Development Administration (ERDA)*, and at Bolt Beranek and Newman Inc., by EPRI.

Acoustic noise from transmission lines is, like oxidant production and radio frequency interference, related to the corona loss along the line. EHV transmission lines are designed to be essentially corona-free under fair weather conditions. However, during periods when the transmission line becomes covered with droplets of moisture, such as during rain, snow, or fog conditions, the corona process is enhanced and audible noise is produced.

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*Now Department of Energy

3.3.1.1 Noise Generation Mechanisms

During rain or fog, many water drop corona sources are formed on the transmission line conductors. These water drops constitute the prime source of audible noise from EHV transmission lines. Figure 3.3 (from Scherer, H. N., Ware, B. J., 1976) provides a simple illustration of the formation of corona and audible noise due to a water drop on the underside of a transmission line conductor. Step (a) shows the shape of the water drop without electric stress. Step (b) shows the water drop deformed by the electric field, such that corona forms at the end of the drop, where the stress is highest. In step (c), the water drop breaks up and one portion departs from the conductor causing a streamer in the resultant air gap. The nature of the sound associated with step (b) is probably one of hissing or humming, and the sound associated with step (c) is likened to a snapping, sputtering, or cracking.

The humming sound from the corona is primarily at 120 Hz and its harmonics. The alternating voltage excitation of the conductor and the threshold nature of corona, result in the corona being produced during short periods during each cycle when the voltage gradient at the discharge site exceeds the corona onset value. The acoustic energy of a positive streamer is much greater than for a negative streamer; however, the average acoustic energies generated in the two half-cycles of the ac line voltage may be comparable. (Trinh, N. G., 1975). Thus the acoustic noise has predominant components at multiples of 120 Hz. Audible noise frequency components in the range of 2-5 Hz are also produced by corona-induced vibration of the conductor (Transmission Line Reference Book, 345 kV and Above, 1975).

3.3.1.2 Quantifying Noise

The basic unit used to measure sound pressure is the pascal which is equivalent to one newton per square meter (N/m^2) Since

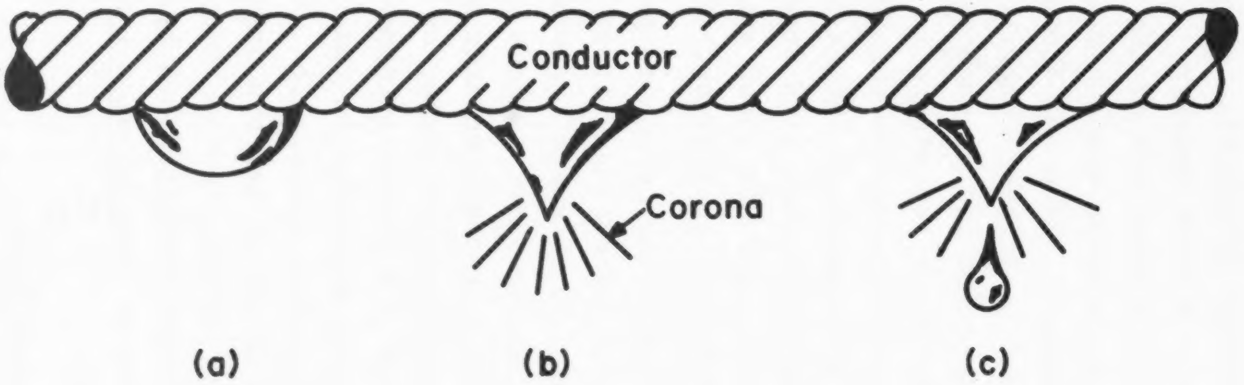
Conductor
Corona
(a)
(b)
(c)

Fig. 3.3 WATER DROPS ATTACHED TO CONDUCTOR
(SCHERER AND WARE, 1976)

human beings can sense sounds over a large dynamic range, such levels are usually expressed in terms of decibels (dB) relative to $2x10^{-5}$ N/m^2 (20 micropascals), which is considered to be the threshold of hearing. The sound level L in dB may be determined by:

$$L = 20 \log_{10} (\text{Sound Pressure in } N/m^2 \ / \ 20x10^{-6} \ N/m^2)$$

3.3.1.2.1 Weighting Networks

The human ear does not have a consistent response over the audio frequency range for a given sound pressure; consequently, weighting factors have been developed to take into account the variations in response. An instrument that measures the weighted sum of all the components of a noise is the sound level meter. The weighting may, for example, be performed by an electrical network in the sound level meter. The weighting network attenuates some frequency components of the noise more than others to approximate how the human auditory system perceives loudness. There are several weighting networks specified by the American National Standards Institute, 1971. Typical frequency-response curves of weighting networks that meet the limits specified by this reference are shown in Figure 3.4 (as curves A, B, and C).

Readings taken with A or B networks are not strictly sound pressure levels because of the weighting; they are therefore termed sound levels. As shown in Figure 3.4, the C network discriminates only against very low and very high frequencies, and is flat between 20 and 4000 Hz.

The A scale is used most frequently to represent the response of the human ear to ordinary noise sources. It is the standard reference for occupational noise exposure as well as other sound descriptors. Sound levels measured using the A-weighting are normally expressed in decibels relative to the reference sound pressure; $P_0 = 2x10^{-5}$ N/m^2. The decibel sound pressure is designated by L_A or dB (A), where

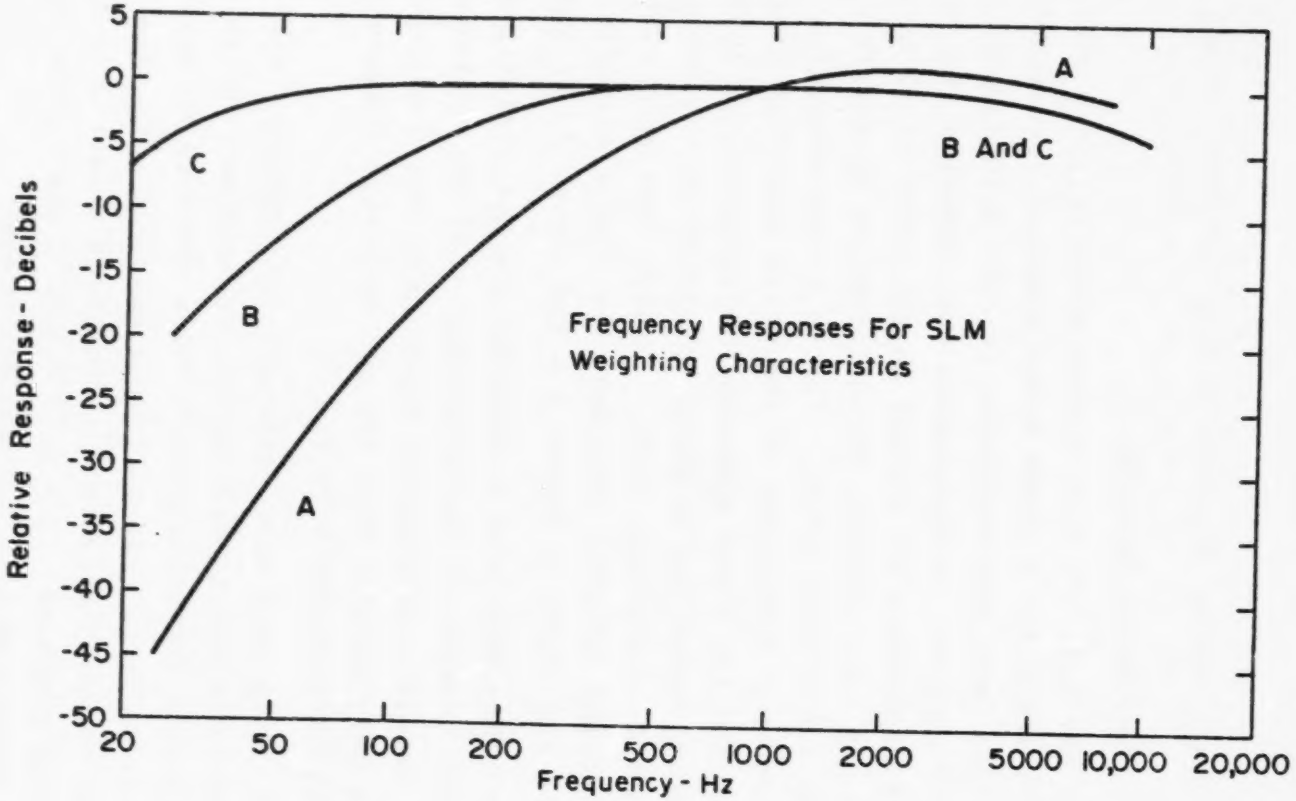

Fig.3.4 FREQUENCY-RESPONSE CHARACTERISTICS IN THE AMERICAN NATIONAL STANDARD SPECIFICATION FOR SOUND-LEVEL METER, ANSI-S1.4-1971

$$L_A = 10 \log_{10} (P_A^2/P_0^2) \quad \text{(dB)}$$

and P_A is the A-weighted sound pressure fluctuation.

3.3.1.2.2 Frequency Analysis

Another method of classifying the frequency composition of a noise consists of dividing the frequency spectrum into various octave or 1/3 octave bands, an octave being the band between any two frequencies having a ratio of 2:1.

The newer and more commonly used set of standard octave bands is defined by center frequencies as follows: 31.5, 63, 125, 250, 500, 1000, 2000, 4000, 8000, and 16,000 Hz.

Octave bands are satisfactory from the viewpoint of specification but are often too wide for practical work in noise control. A complex noise source often has individual sources producing more than one frequency of noise within a particular octave. Therefore, a narrower frequency bandwidth is required to provide adequate definition of the noise produced. Standard bands which are essentially one-third octaves have been developed to meet this need. The one-third octave is sufficiently narrow to define the noise source adequately for most noise control work. Octave or 1/3 octave band frequency analysis can be made with or without using a weighting network.

3.3.1.2.3 Accounting for Time

Much of the noise to which people are exposed is not constant with time. Thus, the A-weighted level which, for example, might be displayed on a chart recording, would not be a constant with time. The recorded line would indicate that the received sound level varies with time, the variations being dependent on the nature of the sound-producing source.

Since the sound level varies with time, standardized procedures have been developed to express the time variability.

For example, an A-weighted decibel level can be found which is exceeded 50% or 90% or 10% of the measuring time. These levels are then denoted L_{50}, L_{90}, or L_{10}. In assessing how annoying a noise is to people, both the average sound level and the range of fluctuation is important.

A single number representation of the equivalent A-weighted noise level over the measurement time is denoted by L_{eq} (also measured with an A-weighted network). L_{eq} is the equivalent steady noise level which would contain the same noise energy as the time varying noise during the same observation period. Mathematically, L_{eq} is given by

$$L_{eq} = 10 \log[1/t_2-t_1) \int_{t_1}^{t_2} P_A{}^2(t)/P_o{}^2 \, dt]$$

and is expressed in A-weighted decibels; where t_2-t_1 is the measurement period, $P_A(t)$ is the A-weighted time varying pressure level and P_o is the reference. The time period for the analysis (t_2-t_1) can vary with the application, but for many standards is over an 8 or 24 hour period.

Since people respond to noise differently during the day than during sleeping hours, procedures have evolved for weighting the night-time noise more heavily. Typically, the night-time noise is given a 10 dB penalty between 10 pm and 7 am. The equivalent A-weighted sound level during a 24 hour period with a 10 dB weighting applied to nighttime sounds is denoted L_{dn}.

Several other rating schemes have been developed for evaluating different noises according to one aspect or another of peoples' subjective response to the noise (see U.S. Department of Housing and Urban Development, Report TE/NA172). Many of these may be applicable to assessing the influence of power line acoustic noise on the subjective response of people.

However, most of the available assessments are based on the more commonly accepted A-weighted characterizations discussed above.

3.3.1.3 Ambient Non-Power-Line Environments

The natural sources of acoustic noise in the environment are myriad. There is some noise associated with all movement or mechanical stressing of materials; and in the normal environment surrounding transmission lines, the major noise source is wind acting upon fixed objects. Some additional noise will be from animals or insects, but this contribution may be small. The background noise will, of course, be highly unpredictable since it is dependent upon many variables, such as weather conditions. Therefore, the natural background noise may vary from a minimum under still, calm conditions to a maximum under conditions of a thunderstorm or windstorm where there is thunder, heavy rain, and high winds. The extreme variability of these conditions makes statistical prediction of the background noise at any particular location an extremely complicated matter.

In addition, the man-made environment also contributes to the background noise levels. All sorts of operating vehicles have intense noise associated with them. Manufacturing facilities can produce high levels of noise in the surrounding area. There are also background noises--people shouting or talking--and noise sources associated with residential areas, such as power mowers or radios. Table 3.3 and Figure 3.5 show the range of the sound levels normally encountered in common environments. The wide range of sound levels to which people are exposed is not limited to occurrences outside the home. Table 3.4 (from U.S. Environmental Protection Agency, 1974) shows a summary of sound levels measured inside 12 homes by the EPA. These measurements specifically excluded areas where the noise resulted from freeways and aircraft. In fact, the internal L_{dn} and L_d

Table 3.3

LEVELS OF SOME COMMON SOUNDS

SOUND POWER, WATTS	SOUND POWER LEVEL dB re 10^{-12} WATT	SOUND PRESSURE, N/m^2	SOUND PRESSURE LEVEL dB re $2x10^{-5}$N/m^2	SOUND SOURCE
3,000,000.0	200	1 atmosphere	194	Saturn rocket.
	185	20000.0	180	
	175		170	
30,000.0	165	2000.0	160	Ram jet.
	155		150	Turbo jet.
300.0	145	200.0	140	Propeller aircraft.
			135	Threshold of pain.
	135		130	Pipe organ.
3.0	125	20.0	120	Riveter, chipper.
	115		110	Punchpress.
0.03	105	2.0	100	Passing truck.
	95		90	Factory.
0.0003	85	0.2	80	Noisy office.
	75		70	
0.000003	65	0.02	60	Conversational speech.
	55		50	Private office.
0.00000003	45	0.002	40	Average residence.
	35		30	Recording studio.
0.0000000003	25	0.0002	20	Rustle of leaves.
	15		10	Threshold of good hearing.
0.000000000003	5	0.00002	0	Threshold of excellent youthful hearing.

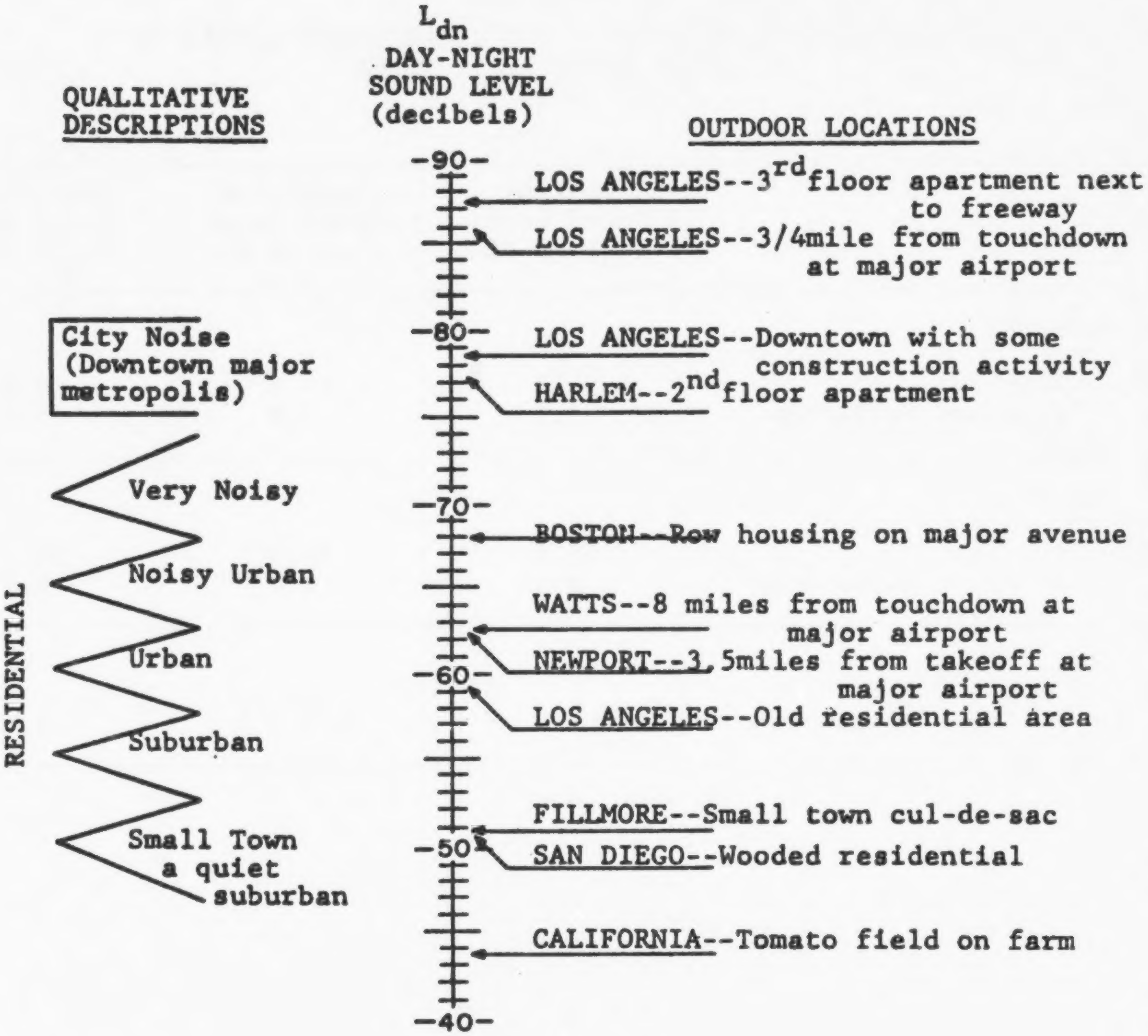

Fig. 3.5 OUTDOOR DAY-NIGHT SOUND LEVEL IN dB re: 20 micropascals (20 micronewtons per square meter) AT VARIOUS LOCATIONS (EPA, 1974)

Table 3.4

COMPARISON OF INTERNAL AND OUTDOOR SOUND LEVELS IN LIVING AREAS AT 12 HOMES

(U.S. EPA, 1974)

	Daytime Sound Level (L_d) in dB	Nighttime Sound Level (L_n) in dB	Day-Night Sound Level (L_{dn}) in dB
Outdoors:			
Average	57.7	49.8	58.8
Standard Deviation	3.1	4.6	3.6
Indoors:			
Average	59.4	46.9	60.4
Standard Deviation	5.6	8.7	5.9
Differences:			
Outdoors Minus Indoors	-1.7	2.9	-1.6

(daytime levels) were slightly higher than those measured outdoors, despite the apparent 18 dB or more average sound level reduction due to the houses.

The EPA has summarized the estimates of the L_{dn} exposures for the urban population as shown in Table 3.5. The median L_{dn} value for the 134 million urban population is 59 dB(A). The remaining population that reside in rural or other non-urban areas is estimated to experience outdoor L_{dn} values ranging between 35 and 50 dB(A) (U.S. Environmental Protection Agency, 1974).

3.3.2 Standards and Guidelines

There are several documented guidelines and standards which have been promulgated or proposed to protect the public health and welfare from environmental noise. None of these documents specifically accounts for any special characteristics which may be inherent in the acoustic noise from power lines. In fact, the data used to generate these documents generally does not include power line noise or studies relating to the subjective reaction to such noise.

3.3.2.1 U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency (EPA) has published (1974) a document entitled Information on Levels of Environmental Noise Requisite to Protect Public Health and Welfare with an Adequate Margin of Safety. The document identifies levels to protect public health and welfare for a large number of situations. The presented levels are not to be construed as standards as they do not take into account cost or feasibility. The states and other political subdivisions retain rights and authority for primary responsibility to control the use of noise sources and the levels of noise to be permitted in their environments. The levels identified provide State and local governments, as well as the Federal Government and the private sector, with an informational point of departure for the purpose of decision-making.

Table 3.5

ESTIMATED PERCENTAGE OF URBAN POPULATION (134 MILLION) RESIDING IN AREAS WITH VARIOUS DAY-NIGHT NOISE LEVELS TOGETHER WITH CUSTOMARY QUALITATIVE DESCRIPTION OF THE AREA (U.S. EPA, 1974)

Description	Typical Range L_{dn} in dB	Average L_{dn} in dB	Estimated Percentage of Urban Population	Average Census Tract Population Density, Number of People Per Square Mile
Quiet Suburban Residential	48-52	50	12	630
Normal Suburban Residential	53-57	55	21	2,000
Urban Residential	58-62	60	28	6,300
Noisy Urban Residential	63-67	65	19	20,000
Very Noisy Urban Residential	68-72	70	7	63,000

The EPA levels document extensively uses the A-weighted energy equivalent sound levels L_{eq} and L_{dn} to define the protection of the public. L_{dn} is weighted by 10 dB during the hours 10 pm to 7 am.

The EPA has determined that virtually the entire U.S. population will be protected against hearing loss from intermittent noise if $L_{eq(24)}$ at the ear is less than 70 dB. The document also identifies levels of interference with human activity and annoynace.

The EPA identifies an L_{dn} of 45 dB indoors and 55 dB outdoors in residential areas as the maximum level below which no effects on public health and welfare occur due to interference with speech or other activity. Speech interference has been identified as the primary interference of noise with human activities. It is one of the primary reasons for adverse community reactions to long term annoyance. The 10 dB nighttime weighting (L_{dn}) is applied to give adequate weight to the generally greater disturbance and annoyance incurred at night. Table 3.6 summarizes the effects associated with an outdoor day-night sound level of 55 dB. The relation used by EPA for reduction in sound level between outdoors and indoors is 15 dB (which is the average sound attenuation and assumes partly open windows). The expected indoor daytime level for a typical neighborhood which has an outdoor L_{dn} of 55 dB is approximately 40 dB, whereas, the nighttime indoor level is approximately 32 dB.

3.3.2.2 U.S. Department of Housing and Urban Development

The U.S. Department of Housing and Urban Development (HUD) has prepared a booklet, Noise Assessment Guidelines, HUD TE/NA 171, and another, Noise Assessment Guidelines Technical Background, HUD TE/NA 172, which sets forth guidelines to provide a "suitable living environment." Table 3.7 presents the HUD interim standard for general external noise exposures. A

Table 3.6

SUMMARY OF HUMAN EFFECTS IN TERMS OF SPEECH COMMUNICATION, COMMUNITY REACTION, COMPLAINTS, ANNOYANCE AND ATTITUDE TOWARDS AREA ASSOCIATED WITH AN OUTDOOR DAY/NIGHT SOUND LEVEL OF 55 dB re 20 MICROPASCALS (U.S. EPA, 1974)

Type of Effect	Magnitude of Effect
Speech - Indoors	100% sentence intelligibility (average) with a 5 dB margin of safety
- Outdoors	100% sentence intelligibility (average) at 0.35 meters 99% sentence intelligibility (average) at 1.0 meters 95% sentence intelligibility (average) at 3.5 meters
Average Community Reaction	None evident; 7 dB below level of significant "complaints and threats of legal action" and at least 16 dB below "vigorous action" (attitudes and other non-level related factors may affect this result)
Complaints	1% dependent on attitude and other non-level related factors
Annoyance	17% dependent on attitude and other non-level related factors
Attitudes Towards Area	Noise essentially the least important of various factors

Table 3.7

EXTERNAL NOISE EXPOSURE STANDARDS FOR NEW CONSTRUCTION
(U.S. Dept. of Housing and Urban Development, TE/NA 172)

GENERAL EXTERNAL EXPOSURES
dB(A)

Unacceptable

Exceeds 80 db(A) 60 minutes per 24 hours

Exceeds 75 dB(A) 8 hours per 24 hours

Discretionary--Normally Unacceptable

Exceeds 65 dB(A) 8 hours per 24 hours

Loud repetitive sounds on site

Discretionary--Normally Acceptable

Does not exceed 65 dB(A) more than 8 hours per 24 hours

Acceptable

Does not exceed 45 dB(A) more than 30 minutes per 24 hours proposed alternate format for HUD's interim acceptability criteria is presented in Figure 3.6. This alternate format expresses acceptability in terms of the cumulative probability distribution of the noise exposure.

The HUD interim standard for interior sleeping quarters, where noise is due to exterior noise sources and interior building sources, lists the noise levels as "acceptable" if they

- do not exceed 55 dB(A) for more than an accumulation of 60 minutes in any 24 hour period;
- do not exceed 45 dB(A) for more than 30 minutes during nighttime sleeping hours from 11 pm to 7 am; and
- do not exceed 45 dB(A) for more than an accumulation of eight hours in any 24 hour day.

3.3.2.3 States and Municipalities

The states of Illinois and New Jersey were the first two states to adopt statewide noise emission limitations based on land use and activity. The state laws employ octave band analysis and dB(A) limits for each land use category and have day/night provisions.

New Jersey regulation has established that between 7:00 am and 10:00 pm 65 dB(A) is the level above which a violation can be cited. As of 1976, for the hours of between 10:00 pm and 7:00 am, the New Jersey Act protects residential properties by establishing a property line level of 50 dB(A).

New York State has proposed noise regulations which limit the daytime sound level in residential areas to 65 dB(A). During nighttime hours (11:00 pm to 7:00 am) in areas where people sleep, the proposed regulation limits the outdoors sound level to 45 dB(A). In addition, restrictions are to be placed on the

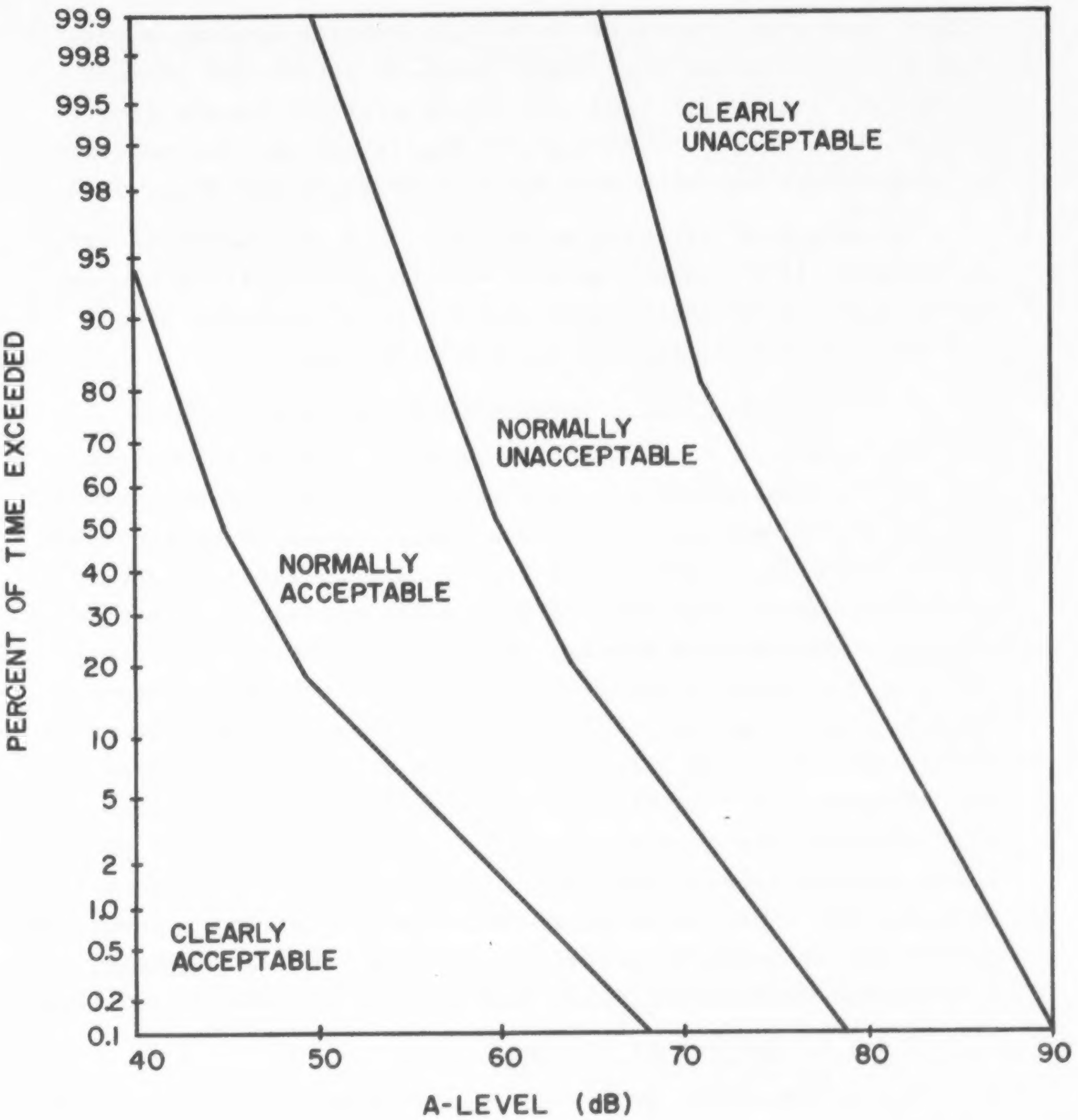

FIG. 3.6 PROPOSED ALTERNATIVE FORMAT FOR HUD'S CRITERION FOR NON-AIRCRAFT NOISE

octave band sound pressure levels (to prevent unusual sound spectra), 1/3 octave band sound pressure levels (to prevent excessive pure tones), and peak sound pressure levels (for impulsive sounds). This proposed regulation and its relation to power lines has been discussed by Driscoll and Haag, 1974.

A summary of existing municipal noise ordinances in 1973, by Bragdon, 1974, showed an average (68 cities) fixed source sound level of 59 dB(A) which was not to be exceeded at residential district boundaries for nighttime use.

3.3.3 Quantifying Transmission Line Acoustic Noise

The study of acoustic noise from EHV transmission lines has been the outgrowth of other corona-related investigations. The earlier investigations into acoustic noise, were conducted in the laboratory, where investigations into radio frequency noise and corona loss effects were being conducted. More recently, comprehensive studies on full-scale three-phase test lines at the Apple Grove 750 kV test project have been conducted (Kolcio, et al., 1973). These laboratory and extensive field tests provided basic information which could be used by the designers of transmission lines to account for various design alternatives on the production of acoustic noise. While these studies provide the basis for most predictions, data from existing EHV lines is being accumulated by individual power companies and is being submitted to the IEEE, who is accumulating a data base on acoustic noise from operating transmission lines.

3.3.3.1 Laboratory Studies

One of the first groups to report on acoustical noise from transmission lines was Taylor, et al., 1969. These investigators conducted tests on the EHV corona performance of lines and had considered some acoustic noise generation effects. The major emphasis in this work was RI (Radio Interference) and corona loss. Some consideration was given to reducing all corona effects by increasing the number of conductors and the individual conductor diameters.

In the 1970-71 time frame, the results of several laboratory studies were published. Juette and Zaffanella, 1970, published data from the General Electric Project UHV. Based on measurements of RI and AN (Audible Noise) measurements on some four conductor test cages, under various weather conditions and voltage gradients, the authors postulated an experimental relationship between RI and the acoustic noise levels. Pokorny, Schlomann, and Barnes, 1972, published the results of a study of the effects of the number of subconductors in a bundle, the diameter of the subconductors in the bundle, and the applied voltage, on the production of both AN and RI. These authors developed a universal curve of AN as a function of the difference between the applied voltage and the noise starting voltage. These authors also noted a decided saturation effect which came into play at higher surface gradients. Laboratory tests reported by Shankle, 1971, showed that audible noise on conductors increases with the size of the conductor for the same gradients, and also increases with the number of subconductors in a bundle for the same gradients and subconductor size. In normal transmission line design, however, the gradient is not a fixed parameter, but varies with the subconductor number and diameter.

The work at Project UHV resulted in publications by Comber and Zaffanella, 1973, 1974, which presented a semi-empirical method of predicting the acoustic noise generated by transmission lines. These papers indicated that the acoustic noise performance of a three-phase line could be predicted by using single-phase test cage data, and they laid the foundation for the prediction of acoustical noise. The procedures of Comber and Zaffanella were refined and appear as Chapter 6 of the Transmission Line Reference Book, 345 kV and Above, 1975.

The audible noise chapter of the Transmission Line Reference Book, 345 kV and Above describes the nature of the noise and the techniques for its measurements. The procedures to evaluate the audible noise of any practical transmission line configuration are shown in detail with equations and charts for an easy, direct evaluation. The evaluation of the random noise component of the audible sound, defined through the dB(A) representation, under heavy rain conditions, can be calculated by use of the presented equations and curves, by a series of seven steps. Examples are also presented on the use of the methodology. The authors also present the methodology for determining the level of the 120 Hz hum of regular bundles in heavy rain.

3.3.3.2 Field Studies

Audible noise experience with their first 500 kV conductor prompted the Bonneville Power Administration to conduct laboratory investigations into the effects of certain design parameters on the audible noise level. The BPA found little correlation between field measured audible noise levels and those predicted from the laboratory tests. In an effort to resolve the discrepancies, the BPA constructed a three-phase test line. The results of tests conducted on this line and from operating transmission lines were reported by Perry, 1971. The tests using this line for various subconductor diameters and numbers permitted the investigators to draw a variety of conclusions, including the validity of using short three-phase test spans to determine accurately the audible noise performance of a transmission line. Under simulated 735 kV operation, Perry determined the A-weighted sound level at 100 ft from the center phase during rain to be 52.9 dB.

Likely, the most comprehensive field data collection effort to date was the Apple Grove 750 kV test project, which was a joint investigation by the American Electric Power Service Corporation and Westinghouse Electric Corporation. Work on this program was reported by Kolcio, *et al.*, 1973. This paper reports the acoustic noise results for the three test lines available at Apple Grove. The three lines used different sized conductors in a four conductor bundle configuration. The paper cites that 26,400 out of 200,000 all-weather records were used to develop an audible noise performance curve for the test lines. Also, a correlation is given of simultaneous readings of audible noise, radio noise, and corona loss. The audible noise results from these tests are presented in a large number of curves of audible noise frequency spectrum for the various lines under various conditions. It was noted that the data presented were obtained without heating current applied to the line. Past experience showed that conductor heating, as is the case when power is being supplied to a load by the line, results in the prevention of water condensation during light fog conditions and speeds up drying after rain and fog. In essence, the conductor heating should reduce the audible noise level during fog.

Based on the Apple Grove data, Byron, 1974, provides estimates of the audible noise level near a typical 765 kV transmission line. These estimates are presented in Table 3.8.

Table 3.8

AUDIBLE NOISE MEASUREMENTS
(Byron, 1974)

Heavy rain	Upper level, 56 dB(A)
Rain	Mean level, 53 dB(A)
Fog	Mean level, 51 dB(A)
Fair weather	Mean level, 37 dB(A)

The data in this table are for a location at the edge of the right-of-way. Results of a study conducted by Truax, 1972, compared a four-conductor bundle with 1.427 inch subconductors with a six-conductor bundle using 1.108 inch conductors. At a distance of 140 ft from the tower center line, the four-conductor bundle resulted in an audible noise of 58.5 dB(A), while the six-conductor bundle produced an audible noise of 51.5 dB(A).

A more recent summary of the Apple Grove test data by Scherer and Ware, 1976, is presented in Table 3.9. The table shows the results of data obtained over a two year period at 775 kV. Over 160,000 audible noise records were analyzed and

Table 3.9

COMPARISON OF THE MEAN AND 95% "A" WEIGHTED LEVELS FOR ONE YEAR AND TWO YEAR DATA

(Scherer and Ware, 1976)

dB(A)

		ONE YEAR		TWO YEARS	
		MEAN	95%	MEAN	95%
RAIN	LINE A	56	59	54	57
	B	57	59	56.5	59
	C	62	64	61	63
FOG	LINE A	49	60	49	59
	B	49	59	49.5	58
	C	59	62	59	62
FAIR	LINE A	43	49	41	52
	B	40	46	40	47
	C	55	57	54	58

of these 58,000 were during rain, snow, and fog. The table shows the data for the three test line configurations and shows the mean level and the level that the noise is below for 95% of the time.

3.3.4 Impact of Transmission Line Audible Noise

The extensive laboratory and field work that has been conducted has resulted in a good understanding of the audible noise levels which will be produced by a transmission line of a particular configuration and voltage. However, the ability to predict the audible noise during the design phase of a transmission line, or the ability to accurately measure the noise produced by an existing line, are only a part of the overall problem. The noise must be related to its impact on people. The noise standards and guidelines which have been discussed, are an attempt to establish noise level limits which will protect the public health and not provide significant annoyance or nuisance to people under its influence. The existing standards and guidelines are not consistent within themselves as a group. In addition, these standards and guidelines have been developed from a vast existing data base of noise levels and the response of humans to the noise from sources that do not have spectral or temporal characteristics similar to the noise produced by the transmission lines. Thus, considerable controversy exists over the application of such standards and guidelines to the noise produced by power lines.

3.3.4.1 Subjective Surveys

One approach to assessing the effect of power line noise on people is to ask those living near existing power lines for their reaction to the noise. Another slightly different method is to register or record the complaints of people residing near the power lines. Neither of these two approaches is very scientific, and many other factors can come into play in determining the person's response. For example, the person's response to the audible noise produced by the power line, can be significantly influenced by his feeling about the presence of the power line, e.g., his experience with the construction crews who installed the line, his satisfaction with the financial arrangements made with the power company in their acquisition of the rights-of-way, and so on.

From the standpoint of complaints of existing EHV lines, testimony by Cohen, 1976, at the New York Hearings related the experience of Hydro-Quebec on this matter. Cohen stated that Hydro-Quebec had ten years of operating experience with 735 kV transmission lines with over 2500 miles of 735 kV line currently in service. He stated that the Hydro-Quebec criterion for audible noise was 50 dB(A) at the edge of the right-of-way under heavy rain conditions. He further stated that there were over 500 homes which are located within 100 ft of the edge of the right-of-way, and that not a single audible noise complaint had been made at any time during the entire history of their 735 kV operation.

Information submitted in response to the Federal Register Notice, concerning surveys of persons living near existing power lines do not shed much light on the impact of the line audible noise on these persons. Busby, et al., 1974, reported on a field survey of farmer experience with 765 kV transmission lines. In this survey, 18 farmers responded to a questionnaire. No specific questions on the questionnaire involved audible noise; however, after the survey sheet was completed by the survey team, additional questions were asked. One question was, "Does the noise of the line bother you?" In reporting the results of the survey, under the heading of noise, it is stated that five of the 18 mentioned noise, especially during periods of rain, snow, or fog. Thus, the survey does not provide a good insight into the farmers' reaction to the line noise. Similarly, a survey undertaken by Upstate Citizens for Safe Energy Transmission (UPSET), 1975, the results of which were supplied in response to the Federal Register Notice, also does not provide a very good indication of how the line noise affects people. It is reported that all 12 persons surveyed reported that the lines made noise, describing it as a buzz, sizzle, hum, hiss, or zap, with the noise increasing during damp, humid weather. This shows that people near the line can hear the noise; however, it does not provide any insight into whether or not the noise really disturbs the people or interferes with important functions such as verbal communications or sleep.

3.3.4.2 Use of Available Data

The prediction of the audible noise levels to be expected from a transmission line under various weather conditions can be agreed upon quite well by the scientific community. However, determining the effect that this noise level will have on people, or how to apply the available data as a function of time in assessing compliance with available noise level guidelines, is a subject of controversy. The lack of agreement as to how to treat available data and predictions is aptly demonstrated by the lack of agreement between various witnesses at the New York State Public Service Commission Hearings.

In assessing the levels to be anticipated from the proposed 765 kV transmission lines, witnesses relied upon the data available from Project UHV and the testing at Apple Grove. Although some disagreement existed on the levels to be anticipated during fog conditions, the differences were resolved by acknowledging the differences in respective definitions of fog. The two areas of interference with human activities were identified as interference with speech and interference with sleep. While complete agreement was not reached on the interference to speech, the major controversy centered on the possible effects of the line noise on sleep. The dichotomy of opinions ranged from the view of Pearsons, 1976, who presented calculations to show that the line adequately adhered to the EPA levels document, and thus would not interfere with sleep, to that of witness Driscoll, 1975, who concluded that from his calculations, incidence of sleep interference may extend to 900 ft from the center of the transmission line during heavy fog or snow.

Although the various methods of treating the available data produced significantly different results, the most salient disagreements existed in two areas. The first is whether the L_{eq} or L_{50} level obtained from the transmission line during the worst case weather conditions, i.e., during heavy rain, should be used for assessing the likely interference of sleep; or whether L_{dn} values should be used. Disagreement existed on whether L_{dn} should be obtained by averaging the line noise obtained during rain over a 24 hr period, or whether the L_{dn} should be obtained by averaging on an annual basis over all weather conditions.

A second major disagreement existed in how much attenuation should be attributed to the sound entering into the sleeping quarters through a partially opened window. The estimates used by different witnesses ranged from a worst case low of 10 dB attenuation to 19 dB attenuation.

The level of noise used as a threshold for sleep disturbance was 35 dB(A); however, some parties felt that this was quite conservative and may not be indicative of a level for sleep disturbance for all types of sounds. That is, the more or less steady sound of the transmission line audible noise may not produce the same response as vehicle traffic having the same equivalent sound level. Other factors which were not felt to be adequately represented in the various analyses presented included the masking effects of wind and rain noise.

Thus, although audible noise levels can be anticipated from EHV transmission lines, it appears that the prediction of these levels is reasonably well understood. However, the use of these levels to predict the human response is not well agreed upon.

3.3.4.3 Psychoacoustics

The problem of assessing the human response to the type of audible noise created by corona on high voltage transmission lines has been recognized and was the subject of a workshop sponsored by the IEEE, in 1974. Papers and discussions presented at this workshop evidenced that the general public responds to the acoustic noise from EHV transmission lines in a different manner than to other common manmade noises, like traffic or airplanes.

Wells, 1974, points out that a possible explanation is that the annoyance due to AN from power lines is not measured very well by using the sound rating systems presently in common use. He points out that the dB(B) is a somewhat better choice than the dB(A) sound measure, from a subjective standpoint. By means of examples, Wells also shows that special purpose rating scales like the Noise Pollution Level (NPL) or Traffic Noise Index (TNI) are not suitable for taking into account the problem of random time variations of the noise. He suggests that another rating, such as the Noise Complaint Potential (NCP) may provide a much better means for taking into account the time variability of the noise.

In addition, Wells concludes:

1. the value of a reasonably precise basic measure lies in the fact that if limits are set using a poor measure, a transmission line that exceeds the specified limit may actually be rated by listeners as much as 10 dB, or more, less objectionable than one which does not exceed the limit;

2. as far as actual human reaction to this type of noise is concerned, the analysis of the subjective effects of time variability is expected to be more critical than the actual choice of a basic measure; and

3. it is suggested that definitive research effort be undertaken to determine the optimum method of rating the time variability of such noise.

In the same workshop, Bragdon and Miller, 1974, review the salient characteristics of power line noise and compare the dB(A) levels of AN to other environmental noise levels. Their conclusions are:

1. The intensity of corona noise relative to other environmental noise sources is relatively minor.

2. Currently, the linear mileage exposure to high voltage lines (500 kV and above) compared to other environmental noise sources constitutes a small degree of exposure.

3. Corona audible noise is generally audible only during rain or fog, a condition which greatly reduces its environmental impact.

4. Compared to other environmental sources, corona audible noise maintains relatively stable high frequency responses, in contrast to other sources, which experience a decrease in response above 2-5 kHz. At low frequencies, the response is similar to other environmental sources.

5. Theoretically, corona audible noise functions as a line source. The fluctuating temporal characteristics (during rain) also result in spatial variations.

6. The fluctuations ($L_{10} - {}_{90}$) of corona audible noise are greater than most environmental noise sources. In addition, corona noise is characterized by a rapid rate of change of fluctuations, while other noise source variations are "slow" with respect to the response time of the human ear.

> Although the present acoustical impact of power transmission lines appears to be minor, as the consumer demand for electrical energy increases, there will be a greater requirement for high voltage power lines. This demand will potentially increase population and land use exposure, which may result in a greater community impact.

A panel discussion at the Psychoacoustics Workshop served as the focal point for airing ideas and questions raised during the workshop sessions. A summary of the panel discussions was prepared by the session chairman, Janischewsky, 1974. Important points brought out in the summary included the recounting that existing or proposed regulations on audible noise are normally developed with noise sources such as traffic and industry in mind. Until the noise from power lines is further studied, regulations imposed could be expected to poorly fit the needs of power lines. Inadequacies of present regulations with respect to audible noise from transmission lines include not accounting properly for the slow variation with time of the noise, which is weather-related and does not depend on the time of day. Another aspect of noise from transmission line corona that is not taken into consideration in present day regulations is the masking effect caused by the rain. There are indications that the effect of noise from the transmission lines is reduced during the rain because it is masked by the noise caused by raindrops hitting objects on the ground. A useful purpose would be served when a specific measure suitable for description of annoyance from audible noise caused by transmission line corona would be developed.

As noted in the introduction to this section, two research programs are now underway to provide a more definitive assessment of the influence of transmission line audible noise on people. These two efforts, sponsored by ERDA and EPRI, will hopefully provide needed basic information on the acceptable noise from transmission lines.

3.4 Radio and Television Interference

3.4.1 Introduction

Radio noise and television interference are corona related phenomena. The problems associated with radio interference were not seriously addressed until the late 1940's, with the advent of operating voltages in excess of 250 kilovolts. Rorden, 1952, notes that the study of this question was started by the Bonneville Power Administration during the war emergency, when short supply of materials created demand for extreme economy. Rorden also makes another point, which has been accepted in transmission line design since that time. He notes that it would be impractical to use conductors that are not in continuous corona in rain.

As the operating voltages increased, radio interference became an important factor in the many compromises necessary in the design of the transmission line, and the choice of the route as well. The level of radio interference that is generated by a transmission line, is a highly complex function of many parameters including atmospheric conditions, conductor size, number of conductors per bundle, operating voltage, and others. Understanding the nature of radio interference, and its relation to specific line parameters, such that the line can be designed to minimize interference problems, has taken many years.

As the transmission line voltages were increased, many studies were conducted, and considerable data was gathered. Lippert, et al., 1958, report extensive tests at the 500 kV level for the American Gas and Electric Company, in which the RI characteristics of bundled conductors consisting of 2, 3, and 4 subconductors were obtained. Later, extensive tests were conducted at the Keystone Project for the purpose of determining a satisfactory conductor diameter with regard to RI for a transmission line at 550 kV, as reported by the Stone and Webster Engineering Corporation, 1963.

The difficulty in obtaining an adequate assessment of the manner in which various parameters influence the generation of radio interference is exemplified in Mather, 1963, who analyzed several thousand sets of readings in an attempt to obtain correlation with the variables of temperature, humidity, barometric pressure, wind, air density, and line voltage. Since wetness was not one of the parameters accurately monitored, adequate causal effects were not obtained in this study. In developing the first 765 kV line, the Apple Grove test facility provided invaluable information on the selection of the conductor size that would permit good radio reception. The work conducted at Apple Grove on radio influence is described in a series of articles by Taylor, et al., 1965; Shankle, et al., 1965; and Kolcio, et al., 1969.

With regard to radio interference, the economics of transmission lines played a major role. Kolcio, et al., 1969, notes that since it would not be economically feasible to use a conductor size that would permit good radio reception for all weather conditions, the present basic philosophy places almost all of the weight on selecting a specific conductor diameter that will allow satisfactory radio reception during fair weather conditions in urban areas. Thus, for EHV transmission lines, some radio frequency interference is anticipated near the line in rural areas, and under conditions of foul weather. The nature of radio frequency interference from transmission lines is such, however, that the interference diminishes rapidly as a function of distance away from the transmission line. Thus, the interference is quite localized near the transmission line.

The fact that radio frequency noise is highly variable with the weather conditions, and falls off very rapidly as a function of distance from the line, are factors resulting in quite varied public response to power line radio frequency noise. In addition, the actual interference experienced by a radio receiver or television set, is a function of the desired signal level at the reception location. The varied response of persons living near EHV transmission lines is exemplified by the results of two farmers' surveys submitted in response to the Federal Register Notice. One, conducted by UPSET, 1975, indicates that of twelve farmers surveyed, ten complained that their TV and radio reception were not as good as neighbors who lived further from the power line. However, the survey conducted by Busby, et al., 1974, resulted in 17 farmers reporting TV reception as good as before the line was installed, one said better, and one reported worse.

Since both the radio frequency noise from the transmission line, and the desired signals, are quantifiable, guidelines for evaluating TVI and RI complaints have been established. An example are those developed by the Bonneville Power Administration, and submitted in response to the Federal Register Notice. This document shows that complaints of radio or television noise can be accommodated within certain limits, to provide those living near the transmission line with reasonable reception.

A TVI or RI complaint must be valid, and the power company must be made aware of the existence of problems if corrective action is to be made. In the survey by Busby, et al., 1974, of 18 farmers, only two knew the utility person to contact for correcting difficulties.

In the following sections, the nature of the electromagnetic noise from transmission lines will be discussed. This will be followed by a discussion of effect of this noise on broadcast reception, and finally a discussion will be presented on the methods used to reduce the impact of such noise on broadcast communications for persons living near transmission lines.

3.4.2 The Nature of Electromagnetic Noise from Transmission Lines

Two types of broadcast signals are of interest to most of the public. These are radio reception and television reception. Radio reception to most people means the use of a standard broadcast-band AM radio receiver. Since the frequency of the electromagnetic signal to be received by these two types of receivers differs significantly, and also since the signal processing and display by the two types of receivers are so different, interference to these two types of services is generally separately discussed.

Previous sections of this report have discussed the electric and magnetic fields associated with transmission lines. The signals received by communications receivers are similar but are higher in frequency and are modulated with information. Thus, the units of measure for radio signals are similar to those noted earlier for fields associated with the 60 Hz transmission line. That is, the basic quantity of interest is the electric field, and its units are volts per meter. However, for radio broadcast signals, the fields are quite weak; therefore, the signal levels are usually stated in microvolts per meter. A microvolt is 1 millionth of a volt.

Both the noise signal from the transmission line and the desired communications signal are usually expressed in terms of microvolts per meter field strength. Since the magnitude of radio frequency signals can vary over a large range, depending on the location of the point of interest with respect to the signal source, the decibel notation is often used, with the signal being expressed in dB relative to 1 microvolt.

The electromagnetic noise from transmission lines which may interfere with broadcast-band radio reception is generally denoted as RI. The noise that may interfere with TV reception is denoted as TVI.

It is important to note that there are two distinct sources for RI and TVI from high voltage transmission lines. These are gap generated noises, and corona generated noise. Gap generated noise is independent of line voltage or design. It results from loose hardware and improperly made connections which act as a source of interference. The location of these discharges can be easily determined and completely eliminated by various techniques, such as are discussed in Loftness, 1974. Gap generated noise, in general, can only be noticed during fair weather, since the gap arcs are usually shorted out during wet weather. Since gap generated noise involves no long term environmental problem and can be adequately resolved by the power companies on a case-by-case basis, the discussions which follow will be principally concerned with the noise produced by corona.

3.4.2.1 Radio Interference--RI

Radio interference--RI, is the term used to denote the electromagnetic noise from transmission lines that exists at frequencies that are below about 10 MHz. From the standpoint of the public, however, the most important frequency range is that between 0.535 to 1.605 MHz. This is the frequency range used for standard amplitude modulated (AM) sound broadcasting. The noise is produced by corona discharges, which occur during the positive half cycles of the transmission line voltage. The CIGRE Working Group 36.01, 1974, shows that by considering the amplitude and duration of the impulsive discharges which occur during various portions of the 60 Hz line voltage cycle, it can be shown that the positive discharges produce approximately 20 dB greater interference in this frequency range than do negative discharges.

Since the radio noise field is primarily determined by the positive impulsive discharges, the nature of the noise field as a function of frequency is related to the temporal characteristics of these positive discharges. The CIGRE Working Group shows that the spectral content of the radio noise is principally below approximately 1 MHz. Above 1 MHz, the field intensity of the noise falls off rapidly. This is illustrated in Figure 3.7, which was obtained from the above CIGRE reference.

For both fair and foul weather, the corona sources are distributed along the transmission line. During foul weather, the discharges are associated with the water drops on the transmission line conductors. The fair weather interference is typically a factor of 10 less than that during foul weather, i.e., a factor of 20 dB. Since under these conditions, incremental sources of interference exist all along the transmission line, the total interference as measured at any point near the transmission line may consist of contributions from impulsive sources extending over some 10's of kilometers along the line.

It has been noted above that the RI due to a transmission line decreases very rapidly as a function of distance away from the transmission line. This is illustrated in Figure 3.8, which was obtained from data presented in the above CIGRE report, and compares the lateral profile of RI from a 765 kV line to that of a 380 kV line, both obtained under rain conditions. They note that the attenuation law for the noise field can be simply expressed as a function of the distance D between the measurement point and the closest conductor as,

$$\frac{E}{E_o} = \left(\frac{D_o}{D}\right)^k$$

where k lies between 1.4 and 1.9 and is a function of the line configuration and the properties of the soil. E_o and D_o are

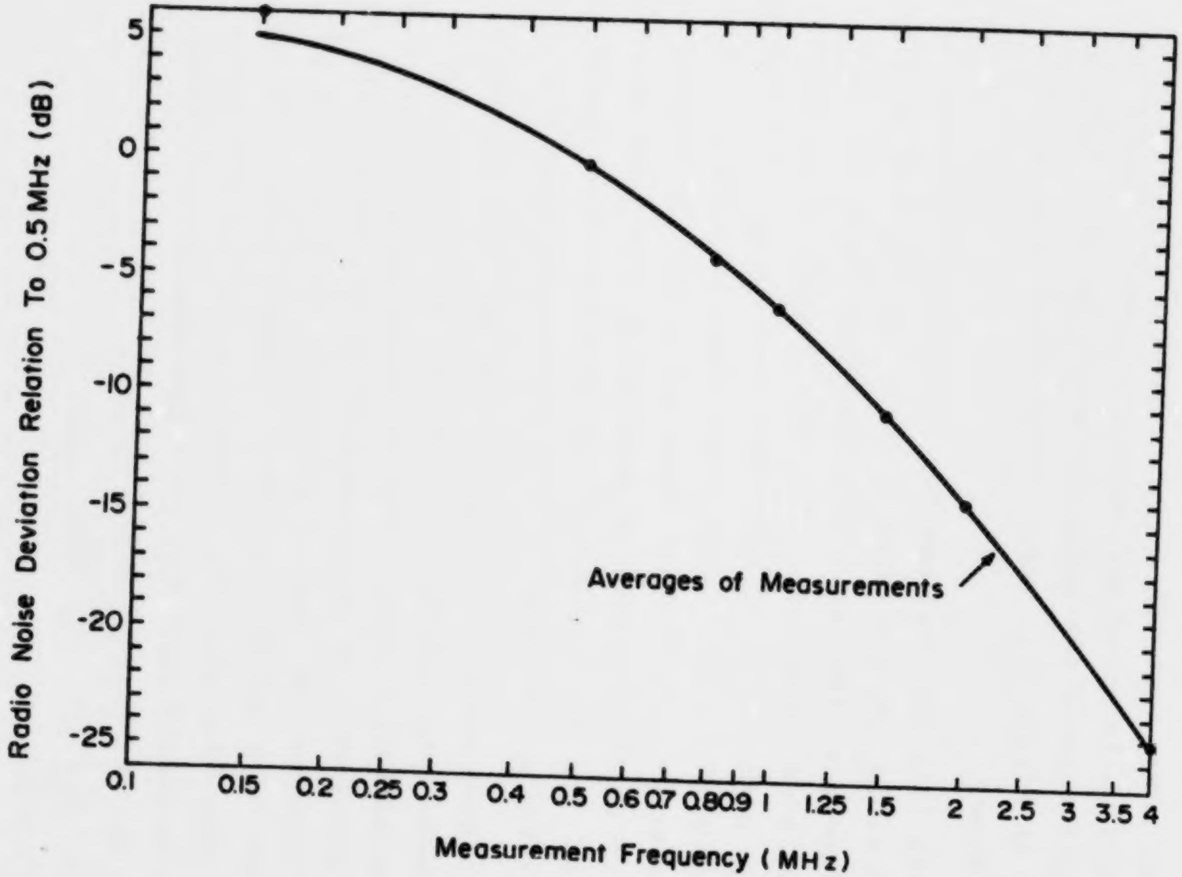

Fig. 3.7 TYPICAL FREQUENCY SPECTRA REFERENCE 0.5 MHz FOR A HORIZONTAL LINE (9 KHz BW) USING A QUASI-PEAK FIELD INTENSITY METER (CIGRE, 1974)

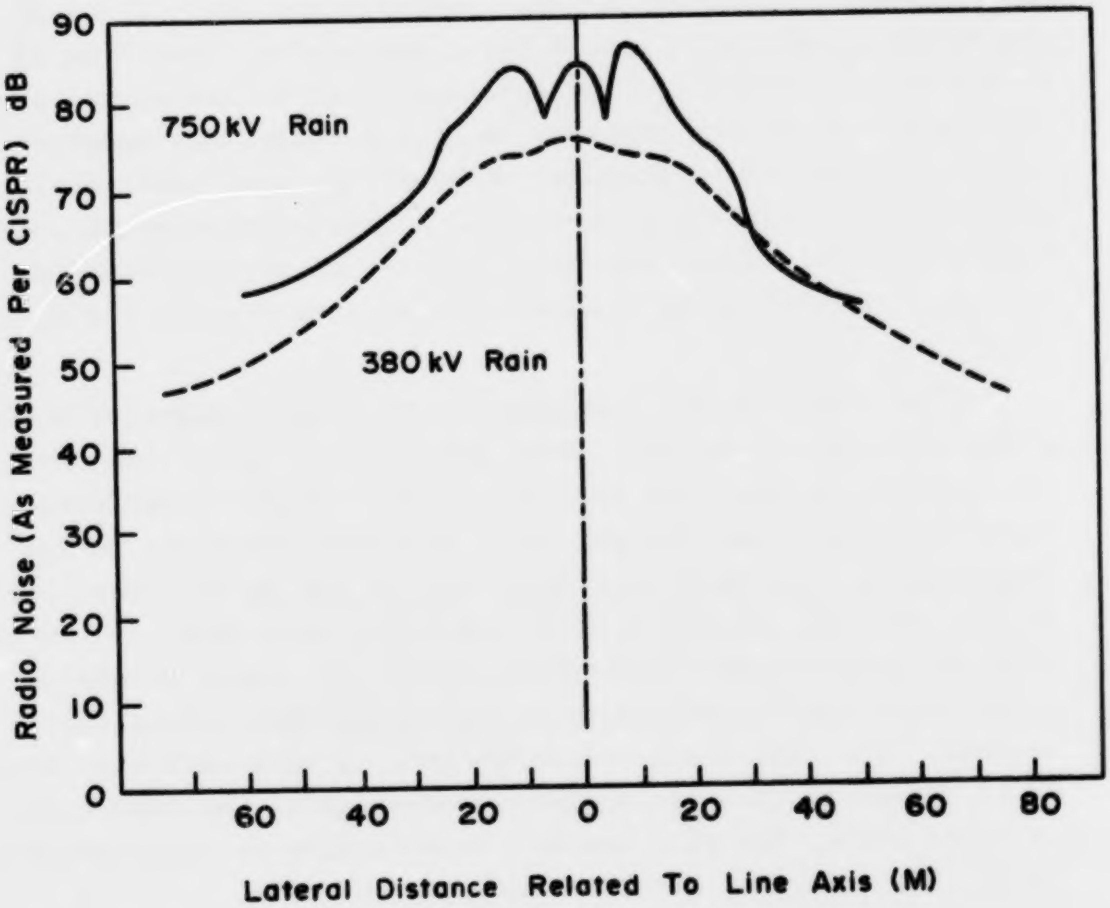

Fig. 3.8 COMPARISON OF RADIO NOISE LATERAL PROFILE MEASUREMENTS OF 765 AND 380 kV LINES WITH HORIZONTAL PHASE CONDUCTORS (Cigre, 1974)

the field and distance, respectively, at a reference point, and E and D are the field and distance to the measurement point.

Both semi-empirical and quasi-analytical methods have been perfected sufficiently that satisfactory predictions of the radio interference levels for transmission lines from 22 to 800 kV are possible. The semi-empirical method emphasizes data developed on the basis of long term recordings under a variety of weather conditions, whereas the quasi-analytical methods employ empirical test results developed on small conductor bundles. These empirical small-line-segment results are then employed using rigorous analysis to predict the interference level.

Shah, 1975, in his response to the Federal Register Notice, notes that the two methods which are commonly used today by the electric utility industry to calculate radio interference, are that of Gary and Moreau, 1971, and that presented in the Transmission Line Reference Book, 345 kV and Above. Most prediction methods usually rely on the heavy rain case as a reference for interference production, since the levels obtained under these conditions are more consistent than during fair weather. The fair weather interference is more variable, since it is dependent upon the surface conditions of the conductors. As noted above, the fair weather interference is approximately 20 dB less than that obtained during heavy rain.

The method presented in the Transmission Line Reference Book..., 1975, for determining the RI from transmission lines, is quite straightforward and easy to use. The procedure presented in this reference uses a series of curves to predict the RI level. A base case is provided for different basic line geometries and operating voltages. The curves for these base cases provide the RI levels as a function of the number of conductors and subconductor diameters. Several additional sets of curves are provided for parameter adjustments from that used in the base case. Included are curves to adjust for

1. voltage departures from base case,
2. bundle diameter variation,
3. variation in phase spacing,
4. variation in average line height, and
5. variation in measurement position with respect to the line.

In a recent paper describing extensive measurements performed on Commonwealth Edison Company EHV transmission lines, Fern and Zalewski, 1977, compared their measurements with calculated values obtained using the procedures of the Transmission Line Reference Book. They note that the calculated radio interference values at a distance of 50 feet from the outside phase conductor were 73.9 dB for heavy rain, 70.9 dB for wet conductor, and 51.9 dB for average fair weather. The corresponding maximum measured values obtained were 70 dB for wet conductor and 50.5 dB for the dry conductor condition (The above values are dB above 1 microvolt per meter). CIGRE, 1974, notes that in practice, the interference level of a transmission line cannot be found with an accuracy better than around ± 2 dB. This applies to both calculated and measured levels.

3.4.2.2 Television Interference--TVI

Interference caused by overhead EHV transmission lines to television reception is, in general, caused by the same mechanisms as is RI, that is, by gap and corona effects. In addition, however, a passive type of interference can be introduced by the presence of the transmission line, due to the rescattering of the desired signal, which causes ghosting. The frequency range of interest for television reception extends from 54 to 890 MHz. This frequency range also encompasses the band of frequencies used for FM broadcast reception.

A general lack of refinement exists for the prediction of TVI as compared to RI. This lack of development may be traced in part to the apparent absence of problems in correctly designed and maintained overhead lines. The first report to the industry on television interference resulting from precipitation on 500 kV transmission lines was made by Clark and Loftness, 1970. CIGRE, 1974, has stated that

> When an overhead line has been correctly designed to prevent radio interference in the frequency range around 1 MHz, interference problems above 30 MHz will be accidental. If interference happens, it will, in most cases, be caused by sparks on insulators and hardware, and seldom by microspark or corona.

This statement may be applicable for typical receiving conditions in the vicinity of a high voltage transmission line. However, Clark and Loftness, 1970, note that due to the high signal-to-noise ratio required for good TV reception, interference situations near the line under foul weather conditions can arise.

To a limited extent, the methods developed for the prediction of RI, can be extended to the TVI region. In essence, based on limited data, the predictions of interference field levels at low frequencies are extended to the TVI range on the basis of a 20 dB per frequency decade roll-off in the field intensity. However, the roll-off in field intensity at the higher frequencies is somewhat countered by the wider bandwidth used in television receivers. Thus, adjustments for the bandwidth are necessary to account for this fact. The Transmission Line Reference Book, 345 kV and Above, presents base case and parameter modification curves for estimating TVI levels.

3.4.3 The Effect of Electromagnetic Noise on Communications

The effect of the electromagnetic noise from EHV transmission lines on radio and television reception is not only dependent upon the noise signal, but is also dependent upon the signal that is desired to be received. Thus, a level of radio noise that, in one location, may not produce any problems at all, can produce significant interference in another area where the signal from the broadcast station is weaker. Shah, 1975, notes that Commonwealth Associates specifies EHV transmission line designs to give grade B reception at the edge of the right-of-way for most radio stations having grade B reception prior to line construction. A pre-construction field survey of ambient radio station signal strengths and an analysis of up to 10 years of weather readings (to determine the mean foul weather radio interference value) is used in this assessment.

3.4.3.1 RI

As noted above, the interfering effect of a noise signal on the reception of a desired signal is a function of both the level of the noise signal and of the desired signal. In fact, it turns out that the ratio of these two signal levels provides a good means for assessing the interfering quality of the noise signal. For standard AM broadcast radio service, the ratio of the desired to noise signal for varying degrees of reception quality has been determined on the basis of subjective listening tests. The IEEE, 1971, presents the results of these listening tests, where EHV transmission line noise was the interfering signal. These results are shown here as Figure 3.9. CIGRE, 1974, presents similar subjective reception quality information. They note that, in practical terms, the higher codes, e.g., 4 and 5 are definable quite precisely in terms of the signal-to-noise ratio. On the other hand, the lower codes 3 to 0 become increasingly subjective and are given largely as suggestions.

The Transmission Line Reference Book notes that a signal-to-noise ratio of approximately 15, or 24 dB meets the Federal

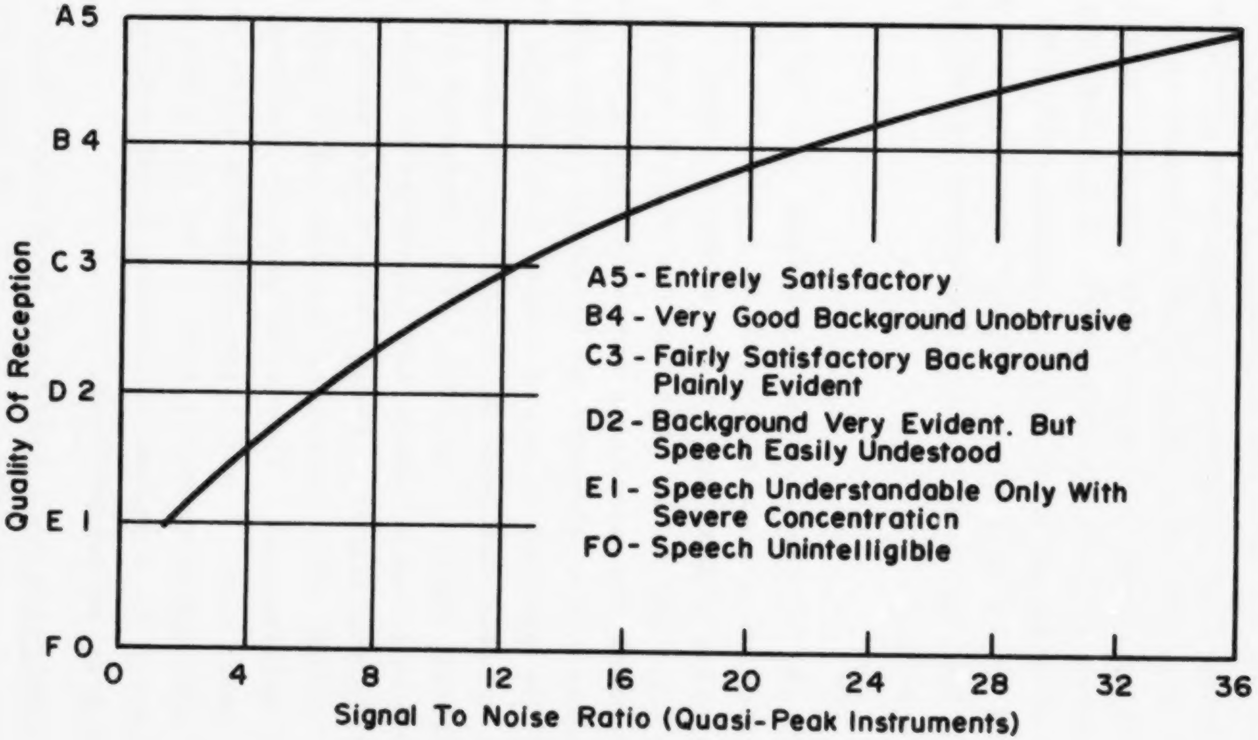

Fig. 3.9 TYPICAL RESULTS OF LISTENING TESTS EHV TRANSMISSION LINE NOISE (IEEE, 1971)

Communication Commission requirement for satisfactory service. This signal-to-noise ratio falls midway between the categories of very good and fairly satisfactory as shown on the curve in Figure 3.9.

The stated signal-to-noise ratio can only define the level of interference, when the level of the broadcast station signal is known. Since the signal that can be received from broadcast stations can vary over wide ranges, depending on the distance to the station transmitter and other factors such as the weather and the time of day, it is generally accepted that the signal-to-noise ratio criterion will only be applied to those stations for which the receiver location is in the primary service coverage area. The primary service coverage area is that in which the ground wave from the broadcasting tower is not subject to objectionable interference from other stations or objectionable fading. Primary service area field strengths for rural areas are taken as those areas where the field strength lies between 100 and 500 microvolts per meter. Thus, based on these field strengths from the broadcast station, and a signal-to-noise for "satisfactory service" of 15, an acceptable level of radio noise from the transmission line at the receiver can be determined.

3.4.3.2 TVI

Clark and Loftness, 1970, note that television interference is, in general, less noticeable on the higher channels. This is due to the roll-off in interference level as frequency increases. They note that for colored television, the interference results in noise bands which drift slowly upward across the screen, when the power frequency is 60 Hz. Bridges, 1976, in his review of the subject, notes that the measurement procedures and the correlation with the subjective response to television interference is not nearly as progressed as for interference to broadcast receivers. Bridges suggests that additional work is necessary in the development of an objective criterion of picture quality under transmission line noise conditions. He also notes that additional work is desired in the development of measurement instrumentation, for the TV frequency range, which will measure a quantity that is closely related to an objective criterion for picture quality.

The Transmission Line Reference Book notes that several investigators have attempted to relate viewer tolerability with signal-to-noise ratio by using conventional radio noise meters. They also note that these investigations have not produced uniform results. Project UHV has conducted subjective viewing tests in an effort to determine a relationship between the quality of reception and the signal-to-noise ratio. From these tests, they determined that a reasonable design criterion would be for the noise to be less than that necessary for "tolerable reception" which corresponds to a signal-to-noise ratio of 17 dB as measured by a peak detector and referenced to a 3 MHz bandwidth. Based on the FCC regulations for the minimum field intensity that must be provided for the principal community to be served by the station, which is 74 dB above 1 microvolt per meter for channels 2 through 6, these investigators determined that a noise field strength of 57 dB (peak) above 1 microvolt per meter in a 3 MHz bandwidth should not be exceeded.

3.4.4 Mitigation

Typical interference mitigation procedures are illustrated in the Bonneville Power Administration Guidelines for Evaluating TVI and RI Complaints. In this document, the BPA states that in order to constitute a valid RI complaint, the signal-to-noise ratio must be 15:1 or below, and the signal strength available from a station must be 100 μV/m or greater. In addition to the above, at least 30% of the radio stations meeting these signal strength requirements must be deteriorated in order for the complainant's location to qualify for corrective action. They note that a complainant for which the above criteria are met for AM broadcast service, will be provided with FM reception where such is available.

CIGRE, 1974, notes that most of the complaints concerning television interference are from viewers whose homes are on the transmitter side of the transmission line. This is a result of ghosting caused by the reflection of desired signal off of the line structure. A typical solution for this case is to use a high gain television reception antenna with a high front-to-back ratio. The use of a higher quality television antenna, or the relocation of the antenna to a tower mast, can often also mitigate the interfering effect of electromagnetic noise from the line. In the reception of distant television signals, the height of the receiving antenna is very important. Jordan, 1950, shows that for the conditions applicable for analyzing practical television propagation and reception, the received signal level is directly proportional to the height of the receiving antenna.

The BPA Guidelines for Evaluating TVI and RI Complaints state that correction for television interference will be made when a reasonable viewable picture would be displayed in the absence of interference, and the signal-to-noise ratio due to interference is below 100:1 with a 500 kHz measurement bandwidth. They note that correction will be assured for no more than a total of four channels, and that correction will normally be limited to that possible from one remote antenna mast per complainant. A more comprehensive reference on TVI mitigation has become available since the Federal Register Notice submissions. This reference is "A Practical Handbook for the Location, Prevention, and Correction of Television Interference from Overhead Transmission Lines," Marvin O. Loftness, 1977.

Thus, while it is not practical to design EHV transmission lines that do not produce any electromagnetic noise, this effect of corona is one of the principal parameters controlling the line design. Even so, under foul weather conditions, RI and TVI may become apparent in certain locations. For those cases where objectionable interference does occur, these situations are normally handled on a local basis rather than to redesign the whole transmission line. These cases are handled by re-orientation, relocation, or replacement of receiving antennas to overcome the interference problem.

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APPENDIX A

RESPONDENTS TO FRL 312-2

In March 1975, the Environmental Protection Agency requested data and information on the health and environmental effects associated with the operation of extremely high voltage transmission lines (FRL 312-2 Federal Register, 40(53): 12312, March 18, 1975.) Over 50 responses totaling over 6000 pages of material were received.

This appendix presents a list of the respondents together with a very brief description of the type of response which was prepared by the EPA. These brief descriptions are intended to be indicative of the content of the response but are certainly not comprehensive or necessarily balanced descriptions of the submitted material. Also shown for each respondent is a File Number. This File Number keys the respondent to the technical information that was submitted. The technical information is listed in Appendix B.

RESPONDENT	FILE NO.	1975 DATE	ENCLOSURES, ATTACHMENTS, AND REMARKS
Mr. Kenneth C. Frank Staff Assistant League of California Cities Berkely, CA	001	03/26	Single page letter requesting information on transmission lines energized below 500 kV.
Mr. Kevin T. McLaughlin Environmental Engineer Power Authority State of NY P.O. Box R Oriskany, NY 13424	002	03/24	Single page letter on terminology
Mr. David H. Askegaard Acting Assistant Administrator Rural Electrification Admin. USDA Washington, D. C.	003	04/03	Single page letter requesting EPA to include summary of effects from 230 kV through higher voltage lines and include DC lines
Mr. F. S. Young Manager, Research Projects Westinghouse Elec. Corp. 700 Braddock Avenue East Pittsburg, PA 15112	004	04/02	Two page synopsis of experience and offer to conduct reimbursable studies.
Mr. J. W. Atman Performance Electrical Prod. Box 12868 Pittsburg, PA 15241	005	04/04	Single page letter with single page attachment describing a Hall Corona Detector.
Mr. Eugene L. Lewis Environmental Coordinator Cahn Engineers Alexander Drive Wallingford, CT 06492	006	04/18	Single page letter transmitting: "A study of environmental aspects of electric transmission and distribution facilities in the state of Connecticut," Vol. 1 - 78 pages, Vol. 2 - 523 pages.
Mr. Frank A. Denbrock Group Vice President Commonwealth Associates 209 E. Washington Avenue	007	04/14	Single page letter transmitting: "Qualifications for: EHV-UHV transmission line environmental research, effects on human, animal, insect and plant life," about 100 pages.
Dr. John H. Williams Ohio Power Siting Commission P.O. Box 1735 Columbus, OH 43216	008	04/15	Single page letter noting a cooperative study with Dept. of Dairy Science, OSU has started to examine EHV effects on milk production, fertility and behavior of dairy cattle.
Mr. Marvin S. Blair Director of Regulatory Compliance Omaha Public Power Dist. 1623 Harvey Omaha, NB 68102	009	04/28	Single page letter noting no 765 kV lines in Nebraska, hence no comment

RESPONDENT	FILE NO.	1975 DATE	ENCLOSURES, ATTACHMENTS, AND REMARKS
Mr. J.D. Voytko, Manager Terrestrial Resources Westinghouse Elec. Corp. Box 1899 Pittsburg, PA 15230	010	04/24	Single page letter submitting copies of 24 reports.
Mr. Wallace J. Alspack NBS Electromagnetics Div. National Bureau of Standards Boulder, CO 80302	011	05/13	Single page letter with single page attachment describing development of electromagnetic field probes for frequencies above 10 MHz.
Mr. William L. Flournoy, Jr. Wake County Planning Dept. Room 900 Courthouse Raleigh, NC 27601	012	05/19	Single page letter which points out that localities could be required to establish minimum set-back requirements if hazards are found.
Mr. Don W. Deno Project UHV General Electric Co. Pittsfield, MA 01201	013	05/07	Two page letter pointing out commercial availability of an electric field strength meter.
Mr. Bob Simpson Staff Counsel New York Public Service Commission 44 Holland Avenue Albany, NY 12208	014	05/07	Two page letter pointing out NYSPSC has two applications pending for construction of 765 kV lines. Hearings will be held and copies of prefiled testimony will be sent when available. (Note prefiled testimony received March 11, 1976)
Mr. Rodger F. Duffy Planning Director Armstrong County Planning Division 402 E. Market Street Kittanning, PA 16201	015	05/28	Single page letter requesting information.
Mr. Alfred C. Herschel 35 Chapel Street Augusta, ME 04330	016	06/07	Two annotated newspaper articles, one on radar disabled veterans the other on microwave irradiation of the American embassy in Moscow.
Mr. Kenneth A. Busby State of New York Department of Agriculture and Markets Building 8, State Campus Albany, NY 12235	017	06/06	Single page letter transmitting, "A field survey of farmer experience with 765 kV transmission lines," 10 pages.
Mr. Elbert Tabor Office of Air Quality Env. Protection Agency Research Triangle Park, NC	018	06/09	Submission of ozone study, "Determination of corona ozone production by high voltage power transmission lines."

RESPONDENT	FILE NO.	1975 DATE	ENCLOSURES, ATTACHMENTS, AND REMARKS
Mrs. John I. Waterman Special Assistant to Senator Hugh Scott United States Senate Washington, DC 20510	019	04/07	Single page letter transmitting single page letter from Mr. Robert E. Sentgeorge, President Concerned Citizens of (Butler County) Penn. Township with attached consultants report, 13 pages.
Dr. Alwyn Scott Department of Electrical and Computer Engineering University of Wisconsin Madison, WI 53706	020	06/09	Two page letter indicating that the impact of EHV fields on the following should be investigated: latent or incipient epilepsy, pacemaker, nervous system development, psychological effects, and shocks.
Mr. Joseph M. Farley Southeastern Electric Reliability Council P.O. Box 2641 Birmingham, AL 35291	021	06/19	Four page letter indicating EPA study not needed; outlines activities of Electric Power Research Institute, Energy Research and Development Administration, IEEE groups, utility systems, and CIGRE; includes list of 19 references.
Dr. Stephen A. Sebo Department of Electrical Eng. Ohio State University Columbus, OH 43210	022	06/20	Single page letter transmitting paper on ozone from EHV lines.
Mr. Stephen B. Ross Charles Yulish Associates 229 Seventh Avenue New York, NY 10011	023	06/17	Single page letter transmitting draft copy of report titled, "Electric transmission lines: how do they affect the environment?" 31 pages.
Mr. Scott M. Bailey, P.E. 1903 Eastlawn, Apt. 11B Midland, MI 48640	024	06/15	Single page letter referring to Russian data, loss of a law suit in Michigan by a power company, and indicating need of EPA to take action to prevent hazards.
Mr. J. N. O'Neal Acting Administrator Bonneville Power Admin. P.O. Box 3621 Portland, OR 97208	025	06/17	Single page letter noting plans of BPA to construct a 1100 kV prototype line, and including a six page report titled, "Environmental impact of overhead transmission lines," and 15 references.
Mr. J. P. McClusky Commonwealth Edison P.O. Box 767 Chicago, IL 60690	026	06/27	Single page letter transmitting two papers and two letters; letters concern audible noise and information for farming under transmission lines respectively.
Mr. Arthur Levy Battelle 505 King Avenue Columbus, OH 43201	027	06/25	Single page letter transmitting article on oxidant measurements

RESPONDENT	FILE NO.	1975 DATE	ENCLOSURES, ATTACHMENTS, AND REMARKS
Mr. Frank A. Jenkins Duke Power Company P.O. Box 2178 Charlotte, NC 28242	028	06/25	Two page letter addressing same points raised in file 021 above.
Dr. Harry A. Kornberg Electric Power Research Inst. 3412 Hillview Avenue Palo Alto, CA 94303	029	06/13	Two page letter with 7 attached references and descriptions of ongoing research work.
Mr. Robert W. Flugum Energy Research and Development Administration Washington, DC 20545	030	06/27	Three page letter detailing ERDA's interests and responsibilities and enclosing scopes of work for electric field effects and electric field measurements proposals.
Mr. H. C. Anderson IEEE Power Engineering Society P.O. Box 4 Schenectady, NY 12301	031	06/26	Two page letter detailing sources of information such as EPRI, CIGRE, power companies, and equipment manufacturers and offer to assist by providing technical information.
Mr. E. D. Callahan Columbia Gas System Service Corporation 20 Mountchanin Road Wilmington, DE 19807	032	06/27	Four page letter pointing to problems associated with design, operation, and maintenance of pipelines in the vicinity of high voltage transmission lines, suggests possibility of joint study and encloses selected bibliography of 9 items.
Mr. Owen A. Lentz East Central Area Reliability Coordination Agreement P.O. Box 102 Cantor, OH	033	06/27	Two page letter addressing ECAR's interests; expresses view that concern is legitimate but that request for "views on criteria... for discharge limits is premature;" suggests that a procedure be established for review of preliminary assessment by interested parties.
Dr. R. E. Kary Arizona Public Service Co. P.O. Box 21666 Phoenix, AZ 85036	034	06/27	Single page letter with an attached compilation of work that has been done in areas addressed in FRL-312-2.
Mr. Thomas A. Phemister Association of American Railroads Washington, DC 20036	035	06/30	Three page letter on subject of the influence of electric supply lines on railroad communications and transmittal of two references (see file 044).
Mrs. Louise B. Young 755 Sheridan Road Winnetka, IL 60093	036	--	Sixteen page letter report titled, "Report to the U.S. Environmental Protection Agency on effects of EHV transmission," and copies of her book, *Power Over People*, and her article in *Bulletin of Atomic Scientists*.

RESPONDENT	FILE NO.	1975 DATE	ENCLOSURES, ATTACHMENTS, AND REMARKS
Mr. V. S. Boyer Philadelphia Electric Co. 2301 Market Street Philadelphia, PA 19101	037	06/24	Two page letter transmitting company studies on electrostatic fields, ratio influence, and audible noise from 500 kV line.
Mr. H. W. Wright Pennsylvania Power and Light Two North Ninth Street Allentown, PA 18101	038	06/25	Two page letter transmitting pertinent pages of an Environmental Assessment for a 1180 kV line and a study of multiple use of EHV right-of-ways.
Mr. W. Donham Crawford Edison Electric Institute 90 Park Avenue New York, NY 10016	039	06/30	Single page letter defining the Edison Institute composition and interests
Mr. Dean B. Siefried New York Power Pool 75 West Route 59 Spring Valley, NY 10977	040	06/27	Eleven page letter report addressing areas called out in FRL 312-2; 12 references.
Commander Naval Electronic Systems Command Washington, DC 20360	041	05/23	Single page letter transmitting Final Environmental Impact Statement for Sanguine (Navy's Extremely Low Frequency Communications System) and related material.
Dr. K. R. Shah Commonwealth Associates 209 E. Washington Jackson, MI 49201	042	06/30	Single page letter transmitting 7 page report addressing points raised in FRL 312-2 including 11 references and data on electric field profiles of 525 kV lines.
Mr. R. S. Talton Carolina Power and Light Co. 336 Fayetteville Street Raleigh, NC 27602	043	06/30	Two page letter expressing opinion that EPA "should not embark on the program outlined in the notice (FRL 312-2)."
Mr. Thomas O. Phemister	044	07/02	See file 035; single page letter sending references mentioned in earlier letter.
Mr. Harold N. Scherer, Jr. American Electric Power Service Corporation 2 Broadway New York, NY 10004	045	06/24	Single page letter transmitting letter reports, reprints, and references in following four areas: 1) Measurements and analytical methods for quantifying electric and magnetic fields; 5 page report, 5 reprints, and 14 additional references. 2) Measurements and analysis of induced voltages and currents; 5 page report, 3 reprints, 25 additional references 3) Electric discharge currents; 14 page report, 22 reprints, 43 additional references 4) Health effects; 7 page report, 13 reprints, 13 additional references.

RESPONDENT	FILE NO.	1975 DATE	ENCLOSURES, ATTACHMENTS, AND REMARKS
The Detroit Edison Company 2000 Second Avenue Detroit, MI 48226	046	06/25	A 107 page special report addressing, measurement and analytical methods for quantifying electric and magnetic fields, measurement and and analysis of induced voltages and currents, electric discharge phenomena and health effects. Report contains some 76 references. Two additional published reports on environmental impact of EHV also submitted.
Mr. K. H. Walker Environmental Protection Agency Rochester Field Office, Region II	047	--	Transmittal of article on licensing 765 kV lines in New York.
Mr. Dean B. Siefried New York Power Pool 75 West Route 59 Spring Valley, NY 10977	048	07/14	Addendum to file No. 40.
Dr. Curtis C. Johnson University of Utah Salt Lake City, UT 84112	049	07/09	Transmittal of article on wave length dependent energy absorption in man
Mr. A. C. Fagerland Consumers Power Company 212 West Michigan Avenue Jackson, MI 49201	050	06/25 07/07	A fourteen page report addressing issues raised in FRL 312-2 with 13 references.
Mr. Jim Munafo Upstate Citizens for Safe Energy Transmission (UPSET) RD No. 2 Hermon, NY 13652	051	06	Transmittal of report titled, "Report of Survey Undertaken by Upstate Citizens for Safe Energy Transmission (UPSET) on Effects of High Voltage Power Lines in Northern New York."
Mr. Stanley B. Doremus U.S. Department of Interior	052		Single page letter transmitting comments of Departmental organizations: Bureau of Reclamation, Fish and Wildlife Service, and Bonneville Power Administration (see also file No. 025). Fish and Wildlife submission gives abstracts of 8 related articles.
Mr. T. A. Phillips Chief, Bureau of Power Federal Power Commission Washington, DC 20426	053	07/10	Single page letter outlining responsibilities Federal Power Commission. Necessity for future EHV facilities.
Mr. Daniel B. Childs 1911 Brighton Dam Road Brookville, MD 20729	054	11/28	Single page letter expressing concern about EHV line from Mt. Airy to Brighton, MD and enclosing an article from Nov. 10 *Washington Star*, titled "ultra-high-voltage lines: danger at a distance."

APPENDIX B

TECHNICAL MATERIAL RECEIVED IN RESPONSE TO FRL 312-2

This appendix provides an alphabetical listing of technical material received in response to FRL 312-2. The listing was organized by the Environmental Protection Agency during their preliminary analysis of the material. This material consists mostly of published articles, though some technical memorandums and internal reports are included in the list. The original source of an item was not always indicated on the material received. In some cases the original source could be verified independently and this information is included in the list. However, the accuracy and completeness of a citation depends for the most part on the material as originally submitted. The numbers appearing in brackets at the end of the citation identify the source. For example "{055-10}" would be the 10th reference submitted with file 055. The file numbers are included with the list of respondents in Appendix A. Only material actually received appears in the list. A number of the respondents included bibliographies or lists of references. This wealth of material has not yet been compiled and the reader interested in these items is referred to the original submissions.

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Anon., "A discussion of extra high voltage overhead transmission," Commonwealth Edison, Chicago, IL, March 1975 {026-01}

Anon., "A study of environmental aspects of electric transmission and distribution facilities in the State of Connecticut," Vol. 1 and Vol. 2, Cahn Engineers, Inc., Wallingford, CT 06492, November 1974 {006}

Anon., "Air quality criteria for photochemical oxidants," Chapters 3 and 4, USDHEW, Washington, DC, March 1970 {010-22}

Anon., Compilation of Navy Sponsored ELF Biomedical and Ecological Research Reports, Volumes I and II, Report No. EMPRO-2, Naval Medical Research and Development Command, Bethesda, MD, February 1975 {041-05}

Anon., "Electric transmission lines: how do they affect the environment?" (Draft) Charles Yulish Associates, New York, NY, June 1975 {023}

Anon., "Final environmental statement related to the proposed Greenwood Energy Center Units 2 and 3," Section 5.5.1.2, Transmission Lines, U.S. Atomic Energy Commission, Washington, DC, November 1974 {046-03}

Anon., "Grounding of fences and buildings," BPA Transmission Line Standard Specification, Part 12, Chapter 1, Bonneville Power Administration, Portland, OR, 1971 {025-08}

Anon., "Guidelines for evaluating TVI and RI complaints," Bonneville Power Administration, Portland, OR

Anon., "Induced voltages on railroad equipment from 345 kV transmission lines," Detroit Edison, Detroit, Michigan (circa 1971), {044-01}

Anon., Navy Sponsored ELF Biological and Ecological Research Summary, Department of the Navy, Washington, DC, March 1975 {041-04}

Anon., "Radio influence study, 550 kV transmission line project," Stone and Webster Engineering Corp., Boston, MA, September 1963 {037-02}

Anon., "Rules and regulations on labour protection at 400, 500, and 750 kV A.C. substations and overhead lines of industrial frequency," SCNTY, Orgres, 1971 (see Note 1) {010-06}

Anon., SANGUINE System Final Environmental Impact Statement for Research Development, Test and Evaluation, Naval Electronic Systems Command, Washington, DC, April 1972 {041-01}

Anon., SANGUINE System Final Environmental Impact Statement for Research, Development, Test and Evaluation, (Technical Annexes), Naval Electronic Systems Command, Washington, DC, April 1972 {041-02}

Anon., Supplement to the SANGUINE System Final Environmental Impact Statement for Research, Development, Test and Evaluation, Naval Electronic Systems Command, Washington, DC, February 1975 {041-03}

Anon., "Tips on how to behave near high voltage power lines," Bonneville Power Administration, Portland, OR, November 1973 {025-07}

Asanova, T.P. and A.I. Rakov, "The state of health of persons working in electrical field of outdoor 400 and 500 kV switchyards," *Hygiene of Labour and Professional Diseases*, No. 5, 1966 (see Note 2) {010-02}

Balderston, G., and L.E. Zaffanella, "Electric field as a parameter of 750-1150 kV line and substation design--measuring methods, design practices, and plans for future investigations," *Proc. Symp. on EHV AC Power Transmission*, Joint American-Soviet Committee on Cooperation in the Field of Energy, Washington, DC, February 1975, U.S. Dept. of the Interior, Bonneville Power Administration, Portland, OR

Bankoske, J.W. and G. McKee, "Ecological influence of electric fields," Electric Power Research Institute Report EPRI 129, May 1975 {029-04}

Barnes, H.C., "Prepared testimony (American Electric Power EHV experience and supported research," Common Record Hearings on Health and Safety of 765 kV Transmission Lines, Cases 26529 and 26599, New York Public Service Commission, 1976 {014-13}

Barnes, H.C. and V. Caleca, "Initial experiences on the 765 kV system of the American Electric Power Company (U.S.A.)," International Conference on Large High Tension Systems (CIGRE), Paper 31-06, 1970 Session, Paris, France {045-10}

Barnes, H.C., A.J. McElroy, and J.H. Charkow, "Rational analysis of electric fields in live line working," *IEEE Trans. Power Apparatus and Systems*, PAS-86 (4): 482-492 (1967) {045-05} {045-32}

Barnes, H.C. and B. Thoren, "The AEP-ASEA UHV project results to 1973, and planning of a system test station and line," International Conference on Large High Tension Systems (CIGRE), Paper 31-10, 1974 Session, Paris, France {045-01}

Bawain, S.M., R.J. Gavalas-Medici, and W.R. Adey, "Effects of modulated very high frequency fields on specific brain rhythms in cats," *Brain Research*, 58: 365-384 (1973) {010-19}

Becker, R.O., "Prepared testimony (medical and biological significance of exposure to low frequency electric and magnetic fields)," Common Record Hearings on Health and Safety of 765 kV Transmission Lines, Cases 26529 and 26599, New York Public Service Commission, 1976 {014-04}

Bracken, T.D., "Field measurements and calculations of electrostatic effects of overhead transmission lines," presented at 1975 IEEE Power Meeting, San Francisco, CA, IEEE Paper F 75 573-6, 1975 {025-06}

Busby, K., D. Driscoll, and W.E. Washbon, "A field survey of farmer experience with 765 kV transmission lines, November 18-20, 1974," Agricultural Resources Commission, State Campus, Albany, NY 12226 {010-12} {017} {045-33}

Byron, R.A., "Design EHV lines to reduce impact," *Electrical World*, pp. 74-77, January 1974 {045-18}

Carroll, R.E., "Prepared testimony (effects of low level ozone concentrations on man)," Common Record Hearings on Health and Safety of 765 kV Transmission Lines, Cases 26529 and 26599, New York Public Service Commission, 1976 {014-14}

Carstensen, E.L., "Prepared testimony (biophysical evaluation of biological effects of electric and magnetic fields)," Common Record Hearings on Health and Safety of 765 kV Transmission Lines, Cases 26529 and 26599, New York Public Service Commission, 1976 {014-11}

Chartier, V.L., J.F. Roach, and M.L. Fenger, "Ozone and NO_x production rate measurements on four conductor bundles for the American Electric Power Service Corporation," Report No. AST-71-812, Westinghouse Electric Corporation, November 1971 {045-21}

Clark, C.F. and M.O. Loftness, "Some observations of foul weather EHV television interference," presented at 1970 IEEE Winter Power Meeting, New York, IEEE

Cohen, L., "Prepared testimony (Hydro-Quebec experience with 735 kV lines)," Common Record Hearings on Health and Safety of 765 kV transmission lines, Cases 26529 and 26599, New York Public Service Commission, 1976 {014-12}

Corcoran, R.P., "The design of a uniform field electrode configuration for the Waltz Mill Project," Westinghouse Report AST-74-983, September 1974 {029-03}

Dalziel, C.F. and W.R. Lee, "Lethal electric currents," IEEE Spectrum, __: 44-50, February 1969 {010-23}

Deno, D.W., "Calculating electrostatic effects of overhead transmission lines," *IEEE Trans. Power Apparatus and Systems*, PAS-93: 1458-1466 (1974) {025-10}

Deno, D.W., "Electrostatic effect induction formulae," IEEE Paper T 75-203-5, 1975 {025-11}

DiPlacido, J., "Magnetic flux density in the vicinity of overhead transmission lines - computer calculations," Memorandum Report, American Electric Power Service Corporation, New York, NY, May 1975 {045-02}

Driscoll, D.A., "Prepared testimony (effects of audible noise, ozone, induced currents and voltages, and electric and magnetic fields from 765 kV lines)," Common Record Hearings on Health and Safety of 765 kV Transmission Lines, Cases 26529 and 26599 New York Public Service Commission, 1975 {014-17}

Durney, C.H., C.C. Johnson, and H. Massoudi, "Longwavelength analysis of plane wave irradiation of a prolate spheroid model of man," *IEEE Trans. Microwave Theory and Techniques*, MTT-23(2): 246-253 (1975) {049}

Electric Power Research Institute, *Transmission Line Reference Book 345 kV and Above*, Fred Weidner and Son Printers, Inc., New York, NY, 1975 {029-01}

Fern, W.J. and R.I. Brabets, "Field investigation of ozone adjacent to high voltage transmission lines," IEEE Paper T 74 057-6, 1973 {026-02}

Fletcher, J.L., "Prepared testimony (effects of noise on wildlife and domestic animals)," Common Record Hearings on Health and Safety of 765 kV Transmission Lines, Cases 26529 and 26599, New York Public Service Commission, 1975 {041-15}

Formanek, V.C., "An improved ELF electric field probe," IIT Research Institute, Chicago, IL, March 1974 {041-06}

Frey, A.H., "Prepared testimony (effects of 60 Hz power transmission line fields on the nervous system and behavior)," Common Record Hearings on Health and Safety of 765 kV Transmission Lines, Cases 26529 and 26599, New York Public Service Commission, 1976 {014-06}

Freydman, M., A. Levy, and S.E. Miller, "Oxidant measurements in the vicinity of energized 765 kV lines," IEEE Trans. Power Apparatus and Systems PAS-92: 1141-1148 (Paper T 72 551-0), 1973 {010-17} {027} {045-23}

Freydman, M. and C.H. Shih, "Effects of the environment on oxidants production in AC corona," IEEE Trans. Power Apparatus and Systems, PAS-93(1): 436-443 (Paper T 73 407-4), 1974 {045-24}

Gann, D.S. and T.F. LaFrance, "Effect of 60 Hz electrostatic fields on growth and survival of cells in tissue culture," (draft) Johns Hopkins University, Baltimore, MD, October 1974 {029-05}

Hauf, R., "Effects of 50-Hz alternating fields on man," (English translation), Sonderdruck and Elektrotechnische zietung, 26: 318-320 (1974) {010-03} {045-34}

Heibel, J.T., T.L. Sweeney, S.A. Sebo, and J.P. Sponseller, "Measurements of effluents due to EHV transmission line corona, I-field tests," Conference Record, Canadian Communications and EHV Conference, IEEE Report 72-CHO-698-1, pp. 162-163, November 1972 {045-25}

Hackenberry, T.O., "Report on Allegheny power systems 500 kV transmission line to Concerned Citizens of Penn Township," Pittsburg, PA, May 1974 {019}

Hylten-Cavallius, H., "Certain ecological effects of highvoltage power lines, Hydro-Quebec report IREQ-1160, February 1975 {045-35}

IEEE Radio Noise Subcommittee Working Group No. 3, "Radio noise design guide for high-voltage transmission lines," IEEE Trans. on Power Apparatus and Systems, PAS 90: 833-842, 1971 {010-13}

IEEE Working Group on Electrostatic Effects of Transmission Lines, "Electrostatic effects of overhead transmission lines, Part I - hazards and effects," IEEE Trans. Paper 71 TP 644-PWR (1971) {010-24} {025-12} {044-02}

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IEEE Working Group on Electrostatic and Electromagnetic Effects of Overhead Transmission Lines, "Electromagnetic effects of overhead transmission lines: practical problems, safeguards, and methods of calculation," IEEE Paper T-73-441-3, 1973 {025-13}

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